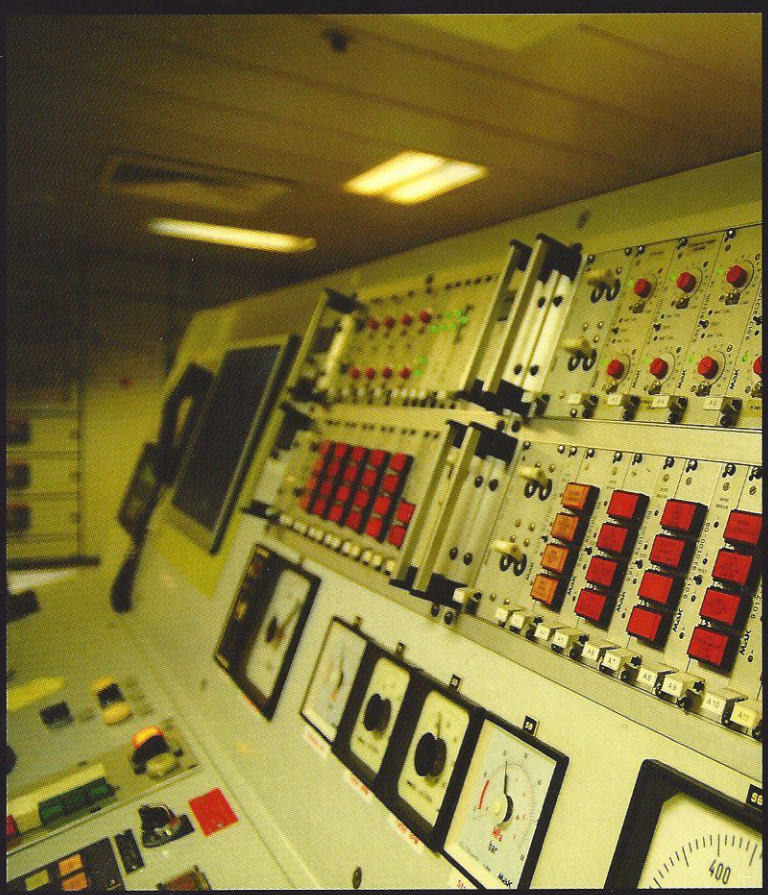
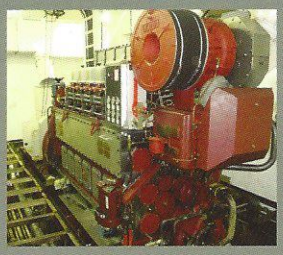
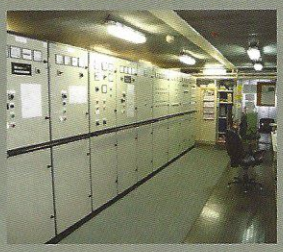
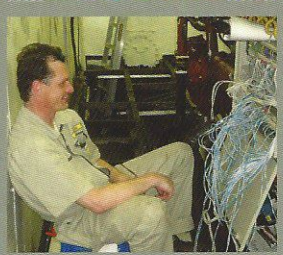
Ship Automation

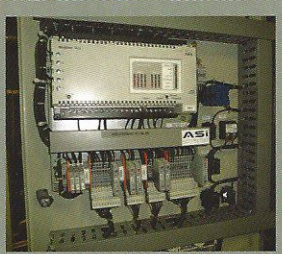
For Marine Engineers & ETOs

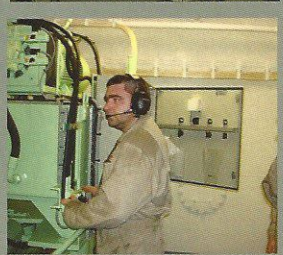












By Alexandr Yakimchuk

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This publication has been prepared to deal with the subject of Ship Automation for Marine Engineers and ETOs. This should not however, be taken to mean that this publication deals comprehensively with all of the issues that will need to be addressed or even, where a particular issue is addressed, that this publication sets out the only definitive view for all situations.

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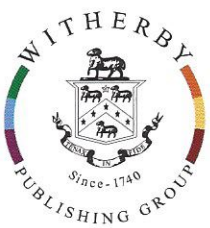

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Ship Automation

For Marine Engineers and ETOs

by

Alexandr Yakimchuk

Preface

While troubleshooting ships' automation and working part time in engine crew training, I decided to write a handbook that would guide marine engineers through the task of troubleshooting.

A major concern was to present material from a practical point of view to avoid or minimise discussions on the theory, instead focusing on showing how to approach the problems of troubleshooting automation in an efficient manner, so that those not skilled in this field could quickly gain some level of proficiency.

This book will introduce you to a variety of modern electrical appliances that are utilised for ships' automation, and while reading it you will progress to read electrical diagrams in the way that skilled electricians do. If you find yourself reading something you already know, read it anyway, you may gain a better foundation for what follows.

Because every paragraph is considered important, do not rush or try to cover a lot of pages in a short period of time. Once you have read each chapter through, you should look at your current ship's diagrams to find out what is common between the explanations and the reality you run into.

However, you will not become a troubleshooter by just reading this book. Learning by doing will always be the best teacher.

People who will find this book useful include:

- Management level marine engineers
- operational level marine engineers
- electricians with a lack of experience and practical skills
- engineering cadets
- electrical engineering cadets.

Good luck and fair troubleshooting,

Alexandr Yakimchuk
PrEng, DipEE., superintendent
Jüngerghans Maritime Services GmbH & CO

Electrical Safety

Everybody who reads this book should understand that maintenance and troubleshooting tasks involve risks. These risks can be reduced by following safety precautions and ensuring there is a safe working environment.

Accidents result in damage to equipment, loss of time, increased costs, personal injury or possibly a fatality.

Electricians and technical personnel must be aware of the dangers that are associated with electrical power and the potential dangers that exist on a job or at a training facility. Never be complacent about personal safety. By practising safe work habits and using common sense, accidents can be avoided.

Disclaimer

The information presented in this book is from the author's own experience and is from a number of sources. Efforts have been made to assure the accuracy of the information, however no warranty is expressed or implied, and no liability or responsibility can be accepted for incorrect information. All information or calculations should be independently verified if in doubt.

In no event shall the publisher and others involved with this publication be liable for direct, indirect or consequential damage resulting from the use of any technique or equipment mentioned herein. No patent liability is assumed with respect to use of information, circuits, illustrations, equipment or software described in this book.

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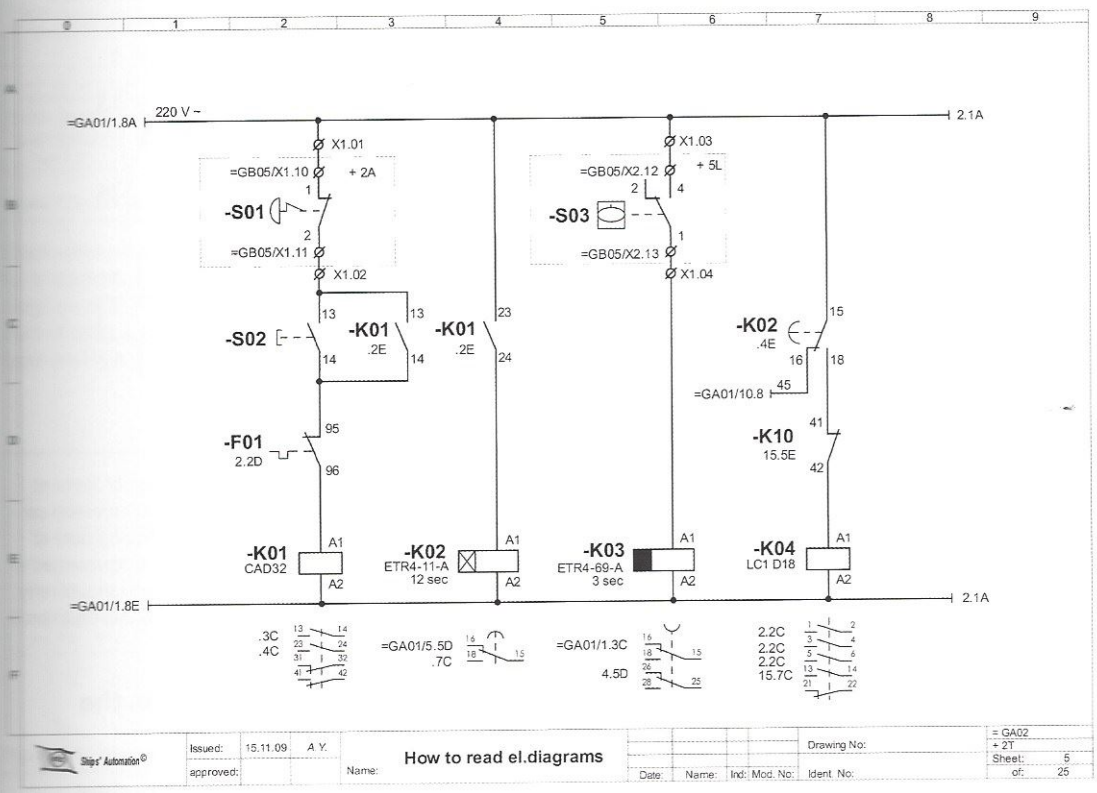
How to Read Electrical Diagrams

1

1 How to Read Electrical Diagrams



1.1 Introduction

Electrical diagrams are schematic illustrations used to represent any electrical system ranging from single line power distribution systems to main power and auxiliary circuits for control, signaling and monitoring. They are composed of symbols representing electrical devices, lines representing conductors or wires for interconnections and can include:

- Symbols that identify the electrical equipment, its component parts and connections
- the electrical equipment and terminal markings
- references at or near the representations of equipment and circuit connectors which indicate where in the schematic diagram the corresponding part of the equipment or the continuation of the circuitry can be found, ie in which section, square or possibly which page.

These features are usually sufficient to explain the circuitry and its mode of operation and can be used to follow through the circuits when tracing a fault. For the engine department, it is important to read and understand them and to use them as an aid while troubleshooting electrical installations. This chapter explains the common rules for drawing electrical diagrams.

1.2 The Method of Representing Circuit Arrangements

Schematic diagrams are broken down according to their functional aspect with the physical location. The mechanical relationships of the component parts of the equipment are usually disregarded. Depending on the extent of the circuitry, several functional units may be shown on the same sheet or a single functional unit may be shown on one or more sheets.

1.3 Markings and Designations

Equipment markings on diagrams are composed as designation blocks (Figure 1.1).

1 Plant identification
2 location of item
3A A - type of item
3B B - number of item
3C C - function of item
4 terminals and conductor markings.

Figure 1.1 – Equipment marking designation

The identification blocks 1 (Plant) and 2 (Location) are always entered in the diagram's block, for example, plant is identified as = *GA02*, location is identified as *+2T* in Figure 1.2.

		Drawing No:	= GA02
			+ 2T
			Sheet: 5
Ind:	Mod. No:	Ident. No:	of: 25

Figure 1.2 – Diagram's block outline

The alphanumeric representation of a code generally reflects the method used for filing and locating the diagrams. Examples of Letter Codes are shown in Table 1.1.

Letter Code	Kind of Item	Examples
A	*Assemblies, subassemblies*	*Amplifier with tubes or transistors*
B	*Transducers*	*Thermoelectric sensor; thermo cell; photoelectric cell; crystal transducer; pick-up*
C	*Capacitors*	
D	*Binary elements; delay devices; storage devices*	*Combinative elements; delay lines; bi-stable elements; mono-stable elements;*
E	*Miscellaneous*	*Lighting devices; heating devices; devices not specified elsewhere in table;*
F	*Protective devices*	*Fuse; overvoltage discharge devices; arrester;*
G	*Generators; supplies*	*Rotating generator; rotating frequency converter; battery; supply device; oscillator;*
H	*Signaling devices*	*Optical and acoustic indicators;*
J		
K	*Relays; contactors*	
L	*Inductors*	*Induction coil; line trap;*
M	*Motors*	
N	*Amplifiers; regulators*	
P	*Measuring equipment, testing equipment*	*Indicating; recording and integrating measuring devices; signal generator; clocks;*
Q	*Mechanical switching devices for power circuits*	*Circuit-breaker; isolator;*
R	*Resistors*	*Adjustable resistor; potentiometer; rheostat; shunt; thermistor;*
S	*Switches; selectors*	*Control switch; pushbutton; limit switch; selector switch; selector;*
T	*Transformers*	*Voltage transformer; current transformer;*
U	*Modulators; changers*	*Discriminator; demodulator; frequency converter;*
V	*Tubes; semiconductors*	*Electronic tube; gas-discharge tube; diode; transistor; thyristor;*
W	*Transmission paths; wave guides; aerials*	*Jumper wire; cable; busbar;*
X	*Terminals, plugs; sockets*	*Disconnecting plug and circuit; test jack; terminal board; soldering terminal strip;*
Y	*Electrically operated mechanical devices*	*Brake; clutch; pneumatic valve.*

Table 1.1 – Functional group identification outline

1.4 Electrical Equipment Representation

Items of electrical equipment and their component parts are denoted by symbols and, where necessary, are interlinked by lines representing connections.

Motor starter units and contacts are shown in the standard reference position, ie in the **non-operated** position with Normally Open (NO) contacts open and Normally Closed (NC) contacts closed (Figure 1.3a) unless exceptions to this rule are specifically marked* (Figure 1.3b).

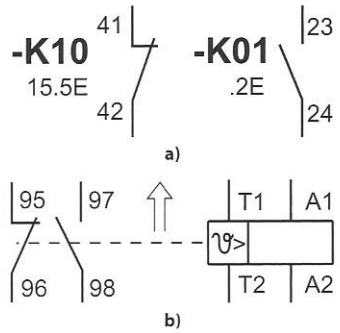


Figure 1.3 – Contact reference position

** The Symbol ⇑ assigned to the contact linkage of Siemens PTC relay SIRIUS 3RN10, shown in Figure 1.3b, represents an exception. The contacts are shown in an operating state of relay that is different from the normal way it is represented in a drawing (DIN 40900, Part 7). In such cases you should refer to Contact Function Digits, which are explained in Chapters 3 and 4.*

1.5 How to Locate an Item in the Schematic Diagram

An electrical drawing is assigned with a sheet number. Each sheet is subdivided into sections listed horizontally as 0, 1, 2, 3, 4 and vertically as A, B, C, D. This arrangement helps to quickly locate a device or contact.

1.6 Diagram Sections and Segments References

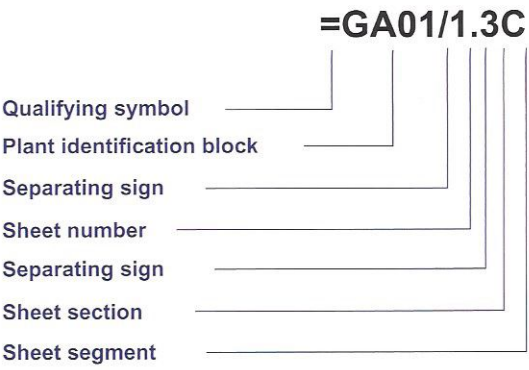


Figure 1.4 – Diagram reference code

When locating an item using the diagram sheets, where a relay coil and contacts are shown through different sheets, reference codes (Figure 1.4) are used.

1.7 Block Diagrams

Block diagrams represent the main arrangements and inter relationships between either different systems or different modules within one system. They create a general overview of the entire plant. Units within a plant, shown in blocks, are connected by cables with their corresponding cable numbers, voltage and number of cores (Figure 1.5).

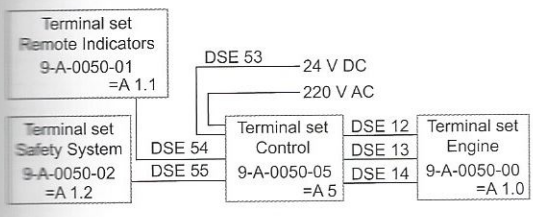


Figure 1.5 – Block diagram outline

Block references consist of: unit reference number, for instance =A1.0 and relative manufacturer's diagram number (9-A-0050-00). Cable reference, as a part of diagrams, consists of: the cable's cores, cable type and the number of incorporated cords.

1.8 Cable Diagrams and Cable Conductor Reference Tables

Grouped cables are reduced to single lines for convenience and then continued in a normal or crossed arrangement, as illustrated in Figure 1.6. The sample illustrates cable *DSE-55*, shown by a heavy line, which connects two appliances (=A1.2 and =A5) into common circuitry. The cable conductors (cores 1 to 10) are shown as light lines.

Any onboard modifications to electrical equipment should be red-lined on the ship's drawing for future reference.

The sample in Figure 1.7 illustrates the entire set of -4KA01 relay contacts. It is not possible to represent both multi-core cable ends on a single sheet. Therefore the cable is split through subsequent diagram sheets as illustrated in Figure 1.7.

For example, cable *DSE-75* has a continuation reference (2.2). The continuation of cable DSE-56 should be found on sheet 3, section 6.

To provide detailed information about the cable's connective features, a table giving the cable's designation will be provided (Figure 1.8).

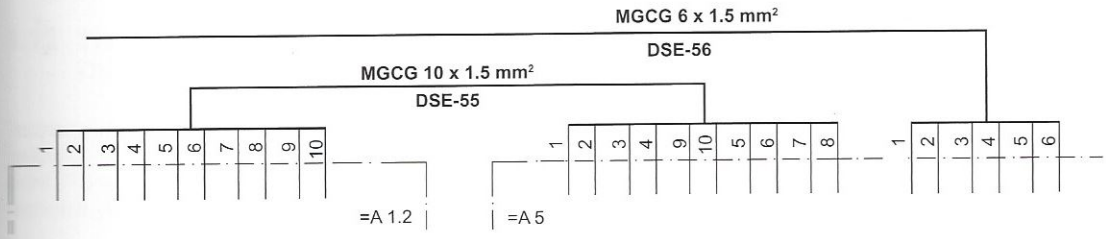


Figure 1.6 – Crossing within a group of connecting lines (cable DSE-55/conductors 1 through 10)

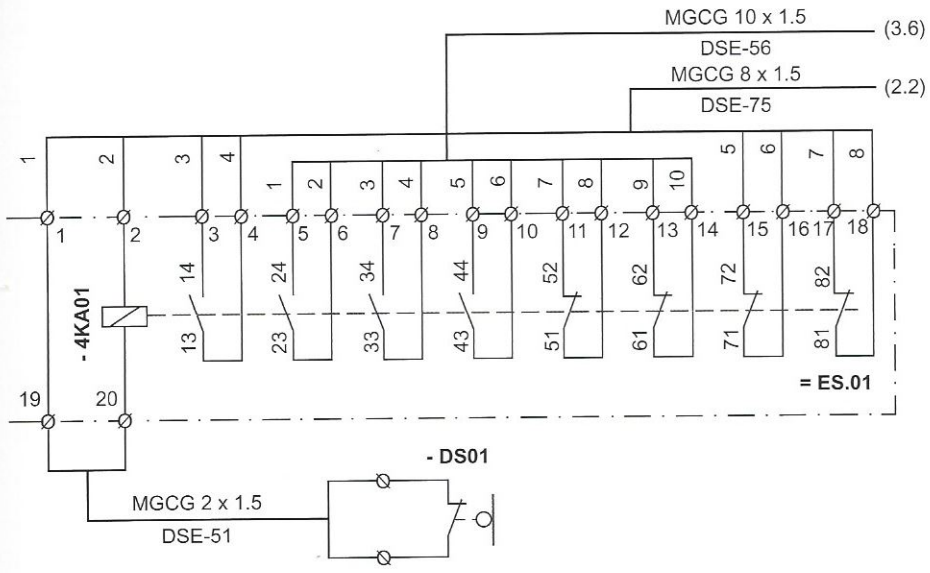


Figure 1.7 – Complete equipment representation (relay -4KA01, plant =ES.01)

Terminal strip																						
Terminal number	X1		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Link			O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
Destination symbol	Connection to:		X55: 1	X55: 2	ALARM: 9184	ALARM: 9184	X5.01: 8	X5.01: 9	X5.01: 10	X5.01: 11	X5.01: 12	X5.01: 20	X5.01: 21	X5.01: 22	X5.01: 23	X5.01: 24	=A10/X1 : 1	=A10/X1 : 2	ALARM: 1250	ALARM: 1250	DS01	DS01
	Designation																					
Cable marking																						
DSE-56	MGCG 10 x 1.5 mm² DIN 89159						1	2	3	4	5	6	7	8	9	10						
DSE-75	MGCG 8 x 1.5 mm² DIN 89159		1	2	3	4											5	6	7	8		
DSE-51	MGCG 2 x 1.5 mm² DIN 89158																				1	2

Figure 1.8 – Cable reference table (DSE-75 cable cords are highlighted for convenience)

1.9 Wire and Conductor Numbering

It is very important that electrical devices in a circuit are connected accurately by using cables with the correct voltage and polarity.

To ensure cables are connected correctly they are given unique numbers (Figure 1.9). This is vital for maintenance and troubleshooting in the event of equipment failure.

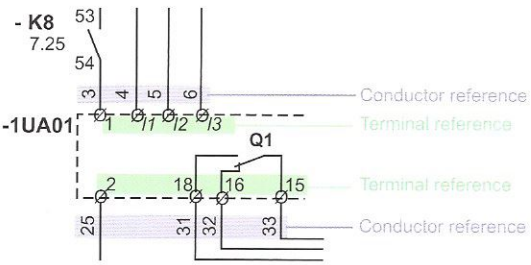


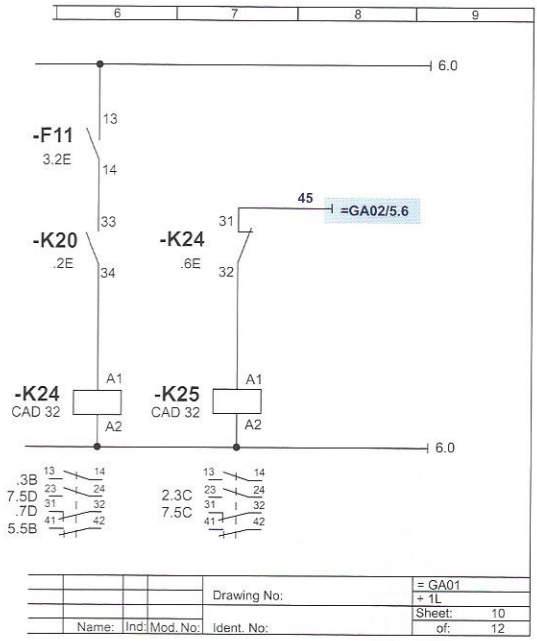
Figure 1.9 – Wiring reference

1.10 Line Break References

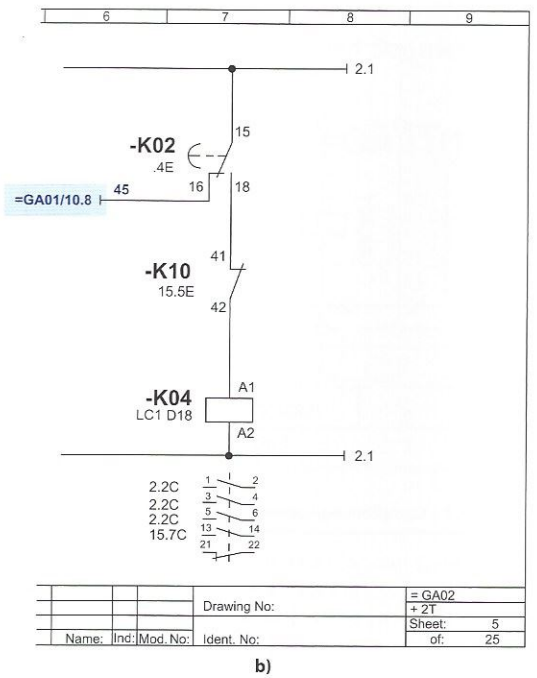
If the line representing a conductor finishes on one sheet, it will have a note indicating where the continuation can be found and can be complemented by a line break identifier, which takes one of the following forms:

- Code as per DIN 42 400 standards, eg 'L1', 'L2', 'PE', 'N'
- a note indicating the mode of operation 'ACKNOWLEDGING', 'EMERGENCY OFF'
- alphanumeric characters representing the conductor tag identifier.

Figure 1.10a represents a line break for the conductor 45, assigned with the tag identifier, this is a line break reference (=GA02/5.6) indicating where the conductor's continuation can be found. The reference points to a different diagram group, therefore it is preceded with a plant identification sign (=). The continuation of the conductor 45 can be located in diagram group =GA02, sheet 5, sector 6, where it is assigned with a reference =GA01/10.8 (Figure 1.10b).



a)



b)

Figure 1.10 – Diagram line break identifiers

1.11 Method of Wiring

Conductors on all electrical drawings are represented by straight lines. Wiring identification markings are illustrated in Figure 1.11.

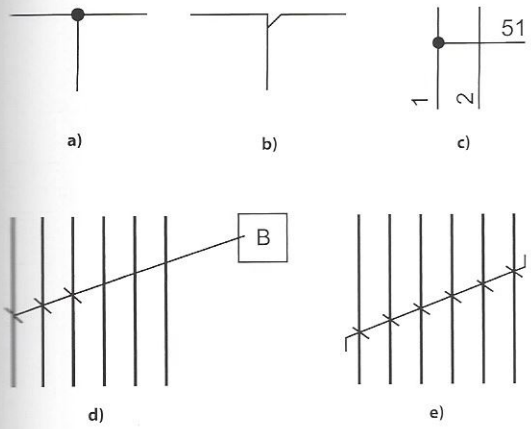
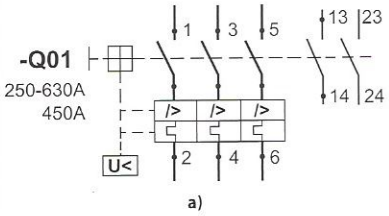


Figure 1.11 – Wiring method:
- **a) and b)** Conductors joined together
- **c)** Conductor 1 is joined with conductor 51, while conductor 2 is passing by
- **d)** Leads run in harness[1] *B* (unmarked leads run in other harnesses)
- **e)** Conductors twisted together

1.12 Technical Data and Type Designations

Technical data and type designations are marked below the equipment identification code in smaller print. Figures 1.12 and 1.13 show samples of technical data designations.



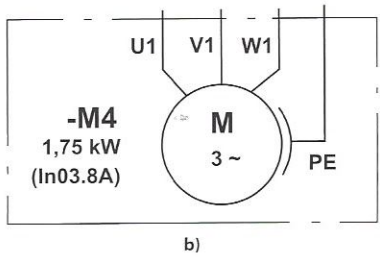


Figure 1.12 – Technical data designation:
- **a)** -Q01 automatic air circuit-breaker and its rated current
- **b)** M4 motor, with its rated output and rated current

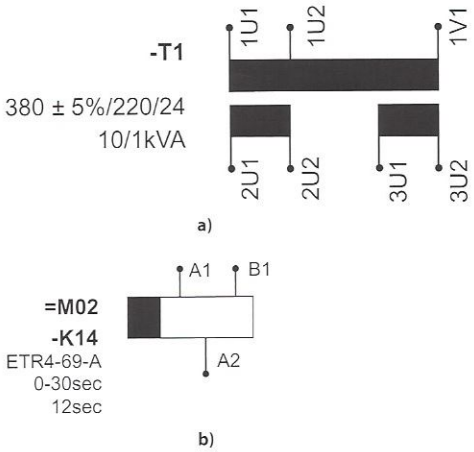


Figure 1.13 – Technical data designation:
- **a)** Transformer, the rated voltage and the capacity
- **b)** Timer, the type, range setting and time gap

[1] A cable or wire harness is a string of cables or wires bound together by damps, ties or are sheaved.

2 Control Elements

2.1 Introduction

The elements of a control circuit include all the equipment and devices that are concerned with the circuit function:

- Enclosures
- conductors
- relays
- contactors
- pilot devices
- protection devices.

Any electrical drawing representing an electrical installation or circuit uses specific symbols to represent the various electrical devices in shorthand. This provides the engineer with an overview of the circuit or installation and is particularly useful for troubleshooting onboard. It is important to be familiar with the various symbols. Some of the commonly used electrical diagram symbols are detailed in this chapter and Appendix 1.

2.2 Electrical Diagram Symbols

Line or ladder diagrams are used to portray control symbols (Figure 2.1), and these are made up of two circuits: the control circuit and power circuit. In this diagram lines represent electrical wires with control circuit wiring shown by lighter weight lines, power circuit wiring is shown by heavier weight lines. A small dot or node at the intersection of wires indicates a connection.

Contact symbols
These are used to indicate open or closed paths of current flow in the system. Contacts are shown as normally open (NO) or normally closed (NC), Figure 2.2. Relay contacts shown by this symbol require another device to actuate them, normally electrical coils.

Figure 2.2 – a) NO contact b) NC contact

The standard way to represent contact is to indicate the circuit condition that is produced when the actuating device is in the de-energised state (DIN 40900, Part 7). For example, in Figure 2.1, relay -K1 is used as the actuating device for the motor starter. The contacts -K1/13-14; 23-24 are shown as normally open, indicating that the contacts are open when the relay coil is de-energised and a completed current path does not exist.

Normally open contact
In Figure 2.1, the circuit is first shown in the de-energised state. The contacts of relay -K1 are shown in their normal state (NO). When the -K1 relay becomes energised, contact -K1/23-24 closes, completing the circuit for the contactor coil -K2. The motor starts as a result.

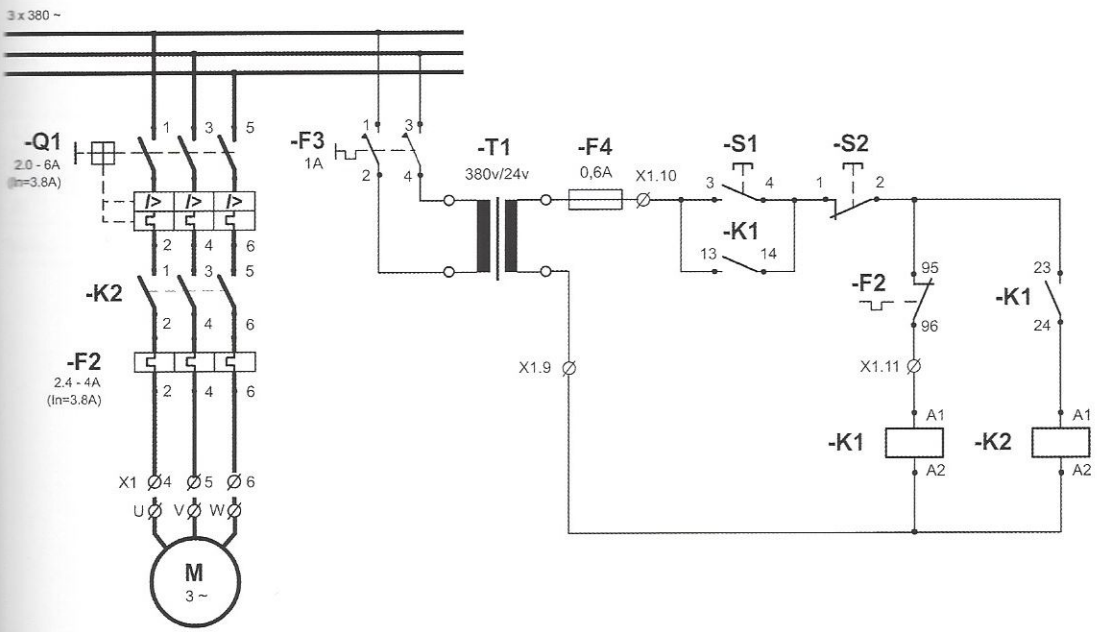


Figure 2.1 – Direct-on-line motor starter diagram

Normally closed contact

In Figure 2.1, overload relay -F2 contact 95-96 is shown as normally closed (NC), this means the contact is closed when the relay is not tripped due to an overload. A complete circuit exists as soon as the start button is pressed and so relay -K1 energises.

Input contacts are either normally open or closed, indicate the binary state of the condition: On or Off (true or false). Variations of simple control circuits are used to represent common logical conditions, Figure 2.3.

Figure 2.3a is called an 'AND' operation circuit. The circuit would be completed, ie the actuator -KM1 energises, if the input conditions of -K1 and -K2 become true (both contacts are closed).

Figure 2.3b represents a circuit called an 'OR' operation circuit. The circuit would be completed if either of the inputs -K3 or -K4 becomes true.

Figure 2.3c represents a circuit called a 'NAND' operation circuit. The circuit would be completed if either or both of the input conditions remain false.

Figure 2.3d represents a circuit called a 'NOR' operation circuit. The circuit would remain completed if neither of the two input statuses change.

Switch symbols

Similar to contact symbols, switch symbols identify open or closed paths of current flow with variations of the symbol representing:

- Limit switches
- foot switches
- pressure switches
- level switches
- temperature-actuated switches
- flow switches
- selector switches.

As with contacts, switches require a device or an operator's action to change their state, eg pressing a light switch.

Pushbutton symbols

There are two basic types of pushbuttons which are momentary and maintained (Figure 2.4). A normally open momentary pushbutton only remains closed while the button is pressed. A normally closed momentary pushbutton only remains open while pressed. A maintained pushbutton will fasten and remain in the changed state when pressed.

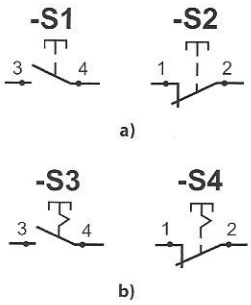


Figure 2.4 – Pushbuttons a) momentary and b) maintained

Coil symbols

Coils are used in a variety of electromagnetic starters, relays and contactors. Letters are used to identify the coil. For example, **-KM** would indicate a motor starter while **-K** indicates both a control relay and contactor (Figure 2.5 a, b).

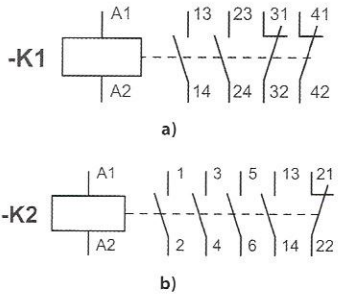


Figure 2.5 – a) Auxiliary relay symbol and b) Contactor symbol

Overload relay symbol

Overload relays protect motors from overheating, eg by machinery being overloaded or an open phase in a three-phase system. The relay will open and disconnect from the power source when too high a current flows in the circuit.

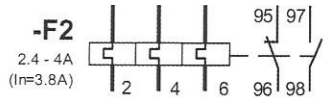


Figure 2.6 – Thermal overload relay symbol

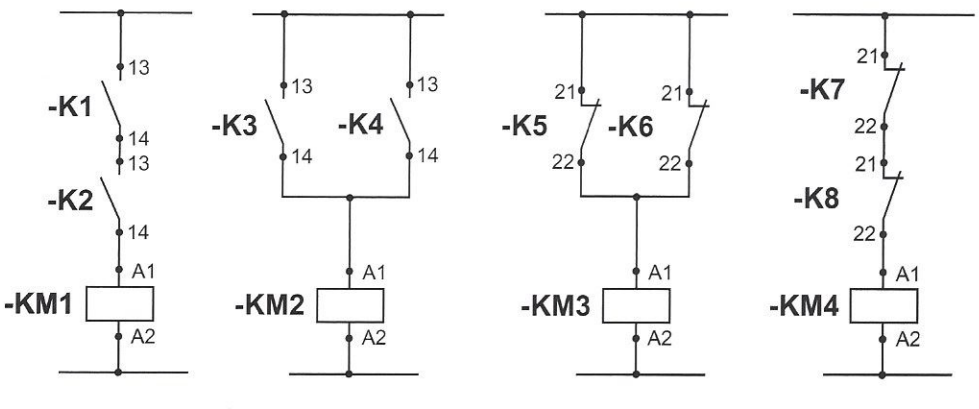


Figure 2.3 – Relays' logic functions

Other symbols
In addition to these symbols, there are many other symbols used in control circuits. Appendix 2 shows a variety of those that are commonly used.

2.3 Abbreviations

The following abbreviations may be encountered in manufacturers' manuals.

AC	*Alternating Current*	***MSP***	*Motor Starter Protector*
ALM	*Alarm*	***MTR***	*Motor*
AM	*Ammeter*	***MN***	*Manual*
ARM	*Armature*	***NEG***	*Negative*
AU	*Automatic*	***NEUT***	*Neutral*
BAT	*Battery*	***NC***	*Normally Closed*
BR	*Brake Relay*	***NO***	*Normally Open*
CAP	*Capacitor*	***OHM***	*Ohmmeter*
CB	*Circuit-Breaker*	***OL***	*Overload*
CKT	*Circuit*	***PB***	*Pushbutton*
CONT	*Control*	***PH***	*Phase*
CR	*Control Relay*	***POS***	*Positive*
CT	*Current Transformer*	***PRI***	*Primary*
D	*Down*	***PS***	*Pressure Switch*
DC	*Direct Current*	***R***	*Reverse*
DISC	*Disconnect Switch*	***REC***	*Rectifier*
DP	*Double-Pole*	***RES***	*Resistor*
DPDT	*Double-Pole, Double-Throw*	***RH***	*Rheostat*
DPST	*Double-Pole, Single-Throw*	***SOL***	*Solenoid*
DT	*Double Throw*	***SEC***	*Secondary*
EOL	*End-of-Line Unit*	***S***	*Switch*
F	*Forward*	***SP***	*Single-Pole*
FREQ	*Frequency*	***SPDT***	*Single-Pole, Double Throw*
FTS	*Foot Switch*	***SPST***	*Single-Pole, Single Throw*
FU	*Fuse*	***SS***	*Selector Switch*
GEN	*Generator*	***SSW***	*Safety Switch*
GRD	*Ground*	***T***	*Transformer*
HOA	*Hand/Off/Auto Selector Switch*	***TB***	*Terminal Board*
IC	*Integrated Circuit*	***TD***	*Time Delay*
INTLK	*Interlock*	***THS***	*Thermostat Switch*
IOL	*Instantaneous Overload*	***TR***	*Time Delay Relay*
JB	*Junction Box*	***U***	*Up*
LS	*Limit Switch*	***UVR***	*Under Voltage Release*
LT	*Lamp*	***VFD***	*Variable Frequency Drive*
M	*Motor Starter*	***XFR***	*Transformer*

Table 2.1 – Control circuit abbreviations

Miniature Relays, Solid State Relays, Control Relays and Contactors

3

3 Miniature Relays, Solid State Relays, Control Relays and Contactors

3.1 Terminal Markings and Contact Designation

Contactor and relay terminal markings (Figure 3.1) should conform to *DIN EN 50005* standard. The markings make it possible to determine the terminals that are associated with the component, the functions they are assigned to and standardise the markings for different manufacturers.

Terminal markings adjacent to main contacts have a single digit reference. Three-phase contactor main contact pairs are designated with: 1-2; 3-4; 5-6.

Terminal markings adjacent to auxiliary contacts have a double digit reference numbers so that:

- The first digit is the contact's position (the position digit) which indicates where the contact is physically situated on the block, ie 1, 2, 3, …, 8
- the second digit defines a contact's function and is called the function digit.

Figure 3.1 – Contactor and relays contacts terminals markings

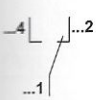
Function digits have been given the following DIN standardised designations (Figure 3.2):

Break contacts (NC) have function digit 1 and 2

Late break contacts (LB) have function digits 5 and 6 also known as 'Normally close Late' (NCL)

Make contacts (NO) have function digits 3 and 4

Early make contacts (EM) have function digits 7 and 8 also known as 'Normally open Early' (NOE)



Change over contacts (CO) have function digits 1-2-4

Figure 3.2 – Contact designations

Each auxiliary contact that is utilised by relays and contactors is clearly designated, the reference numbers are stamped on both sides of the contact terminals.

3.2 Miniature Relays

The relay is an electro-mechanical switch, consisting of a coil, an armature and contacts. (See Figure 3.3).

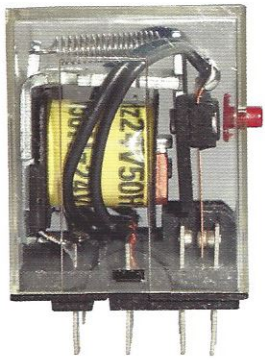


Figure 3.3 – Base-mounted miniature relay

A current passes through the coil creating a magnetic field that attracts the armature, causing the contacts to move, either making or breaking a connection. The following contacts are known by how they can be thrown:

Normally open (NO)
When the relay is activated, NO contacts connect the circuit and will disconnect the circuit when it is inactive.

Normally closed (NC)
NC contacts disconnect the circuit when the relay is activated and connect when inactive.

Change over (CO)
The contacts have a common terminal and control two circuits. One is a NO contact and the other is an NC contact. It is also known as a 'double-throw' (DT).

The following contact designations are also commonly encountered (Figure 3.4):

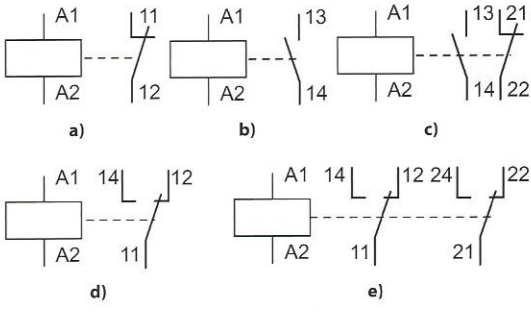


Figure 3.4 – Miniature relay contacts designations

Single Pole Single-Throw (SPST)
These have two terminals that can be connected or disconnected (11–12 or 13–14) and two terminals for the coil. The terminology 'SPNO' and 'SPNC' is sometimes used to indicate the contacts' de-energised state (Figure 3.4a and b).

Double Pole Single-Throw (DPST)
The relay has four terminals that can be connected or disconnected. This is equivalent to two SPST switches actuated by a single coil and has two terminals for the coil (Figure 3.4c).

Single Pole Double-Throw (SPDT)
With a total of five terminals, two for the coil, a further terminal connects to two others as a CO contact (Figure 3.4d).

Double Pole Double-Throw (DPDT)
This has eight terminals with two rows of CO contacts. It is equivalent to two SPDT relays actuated by a single coil (Figure 3.4e).

Miniature relays are also subdivided by their operation:

Non-Latching (stable type)
A relay that is activated when the coil is energised and turns off when de-energised. Non-latching relays are used in control applications when the switch must return to a neutral state if power is lost.

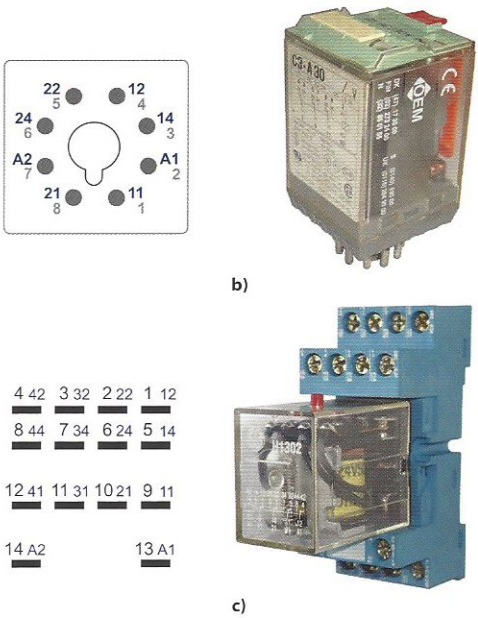
Latching type
Latching relays are used when power consumption and dissipation are limited. For example, after the initial actuation of the relay no further power is needed to maintain the state.

1. One Coil Latching Type
   This relay uses a pulse input to a single coil and a latching mechanism to maintain the contact as either on or off. By applying signals of opposite polarities the relay is set and reset.

2. Two Coil Latching Type
   This relay uses a latching construction and two coils, one to set and another to reset. Setting and resetting is achieved by applying pulse signals of the same polarity.

Miniature relays are designed so that the casing does not become detached under normal use, as performance could be reduced. Consequently, the DIN rail mounting system allows simple replacement of malfunctioned relays. A PCB (Printed Circuit Board) miniature relay is illustrated in Figure 3.5a, socket mounted 'ice cube miniature relays' and their terminal designation are illustrated in Figures 3.5b and c.

a)



b)

c)

Figure 3.5 – Miniature relays terminals' designations

Miniature relays are assembled into control cabinets with their sockets, which can in general be subdivided into two basic types:

- Screw terminals sockets
- screwless terminals sockets (for fast wiring).

All sockets are either panel- or 35 mm rail-mounted (EN 60715). Socket's terminals as well as relays' contacts pins are assigned with reference numbers, which should be used when troubleshooting to verify the contacts' condition in an energized and de-energized state.

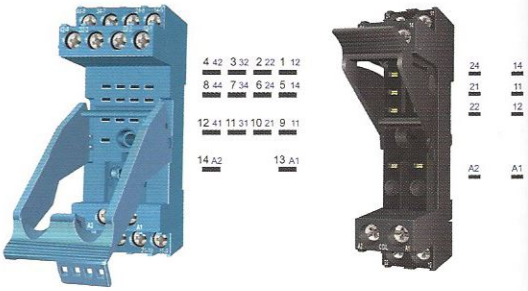


Figure 3.6

3.2.1 Latching Relay

Latching relays allow the circuit to be controlled by using a single pulse to the relay control circuit and are used when a relay is required to maintain its position if the power is interrupted. There are three basic types of latching relay:

Magnetic latching
This relay uses one pulse to move the contacts in one direction. A second pulse from a different input is required to return the contacts. Pulses that are repeated from a single input will not have any effect.

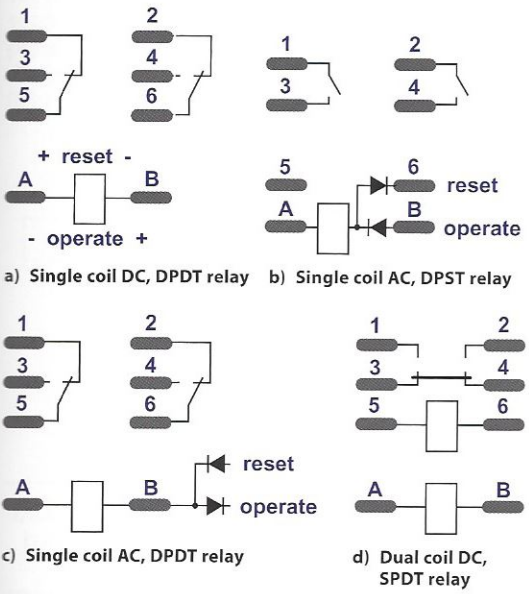
Mechanical latching
This relay uses a locking mechanism to maintain contacts in the set position, a second coil is normally required to change the state. As the latch does not rely on a magnet it does not degrade with time or weaken during thermal cycling.

Impulse Sequencing

Impulse sequencing relays, also known as impulse relays, move contacts with every pulse without redirecting the pulse or reversing the polarity.

Many impulse relays consist of a magnetic latch relay and a solid state steering circuit. When power is applied, the steering circuit determines the position of the relay and the opposite coil is energised, transferring and latching the contacts. When the coil is re-energised the contacts transfer once again.

Features of latching relay wiring are illustrated in Figure 3.7.



a) Single coil DC, DPDT relay b) Single coil AC, DPST relay

c) Single coil AC, DPDT relay d) Dual coil DC, SPDT relay

Figure 3.7 – Latching relay DIN rail base terminal wiring features

3.2.2 Reed Relays (Electromechanical Printed Circuit Board Relays)

A reed relay consists of a reed switch, ie a sealed glass capsule containing two separated overlapping ferromagnetic reeds. A typical reed switch capsule is shown in Figure 3.9. The capsule is surrounded by an electromagnetic coil. When the coil is energised, the contacts that are normally open are brought together. When the coil voltage is removed, the reeds separate by their own spring tension.

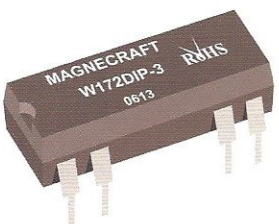


Figure 3.8 – Reed relay

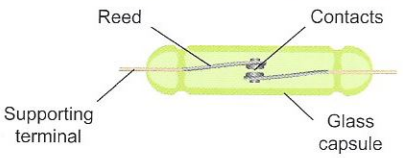


Figure 3.9 – Reed switch

* LED – Light Emitting Diode.

The reeds provide a magnetic operating gap and serve as a contact pair providing NO, NC and CO combinations.

Reed relays have the advantage of being hermetically sealed and as a result are protected from atmospheric contaminants.

To make NC or CO contacts, reed switches will occasionally use permanent magnets for magnetic biasing. The current rating of the reed, normally up to one amp, depends on the size, type and amount of plating.

3.3 Solid State Relays

Electromechanical relays can be expensive, large, take longer to work than modern semiconductors and have a finite contact life, particularly for large power contactor relays. Solid state relays, which use thyristors, also known as Silicon Controlled Rectifiers (SCR), Triodes for Alternating Current (TRIAC) or transistor outputs are used instead.

The output device (SCR, TRIAC, or transistor) is optically-coupled to an LED* light source inside the relay (Figure 3.10).

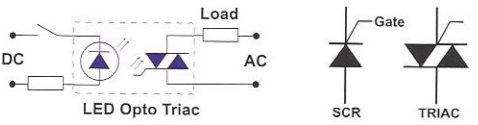


Figure 3.10 – Opto-coupler

Being a solid state there are no moving parts to wear out, no sparking on contact, no contact corrosion and they can be switched on and off quicker than mechanical relays (Figure 3.11). However, they are expensive to build for very high current ratings where electromechanical contactors dominate.

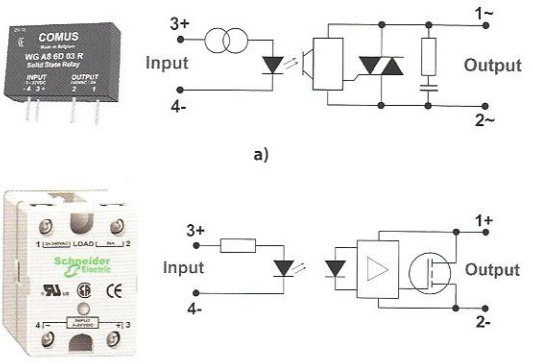


Figure 3.11 – Solid state relays

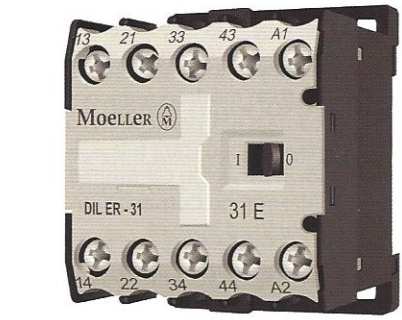
Solid state relays will only open the AC circuit at a point of zero current as their inherent hysteresis (memory) maintains current continuity after the LED is de-energised, until it falls below the 'holding current'. Known as 'zero-crossover switching', this is the advantage of uninterrupted operation during the sine wave when using AC power and avoids large voltage spikes.

A problem associated with SCRs is that they are more likely to fail shorted (or closed) rather than open, as is the case of EM relays. As a 'fail-open' condition is deemed to be safer, EM relays are often preferred for certain applications.

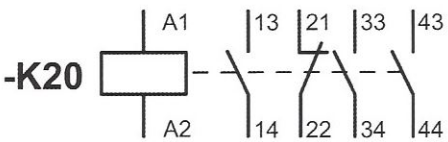
3.4 Control Relays

The contacts of electromechanical devices that are utilised through control circuitry only are unlikely to sustain currents higher than 10 Amps. They are called control relays, but are also referred to as relays (Figure 3.12). Relays are used in control and regulate circuits for the indirect control of electric motors, valves and clutches.

A modular system is formed around functional basic units, consisting of an AC or DC operated drive (coil with armature) and auxiliary contacts.



a)



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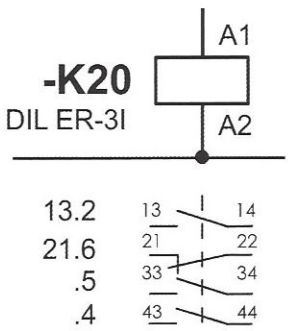


c)

Figure 3.12 – a) Control relay Kl.Moeller DIL ER31 b) Relay symbol c) Relay technical data and type designation as shown in diagrams

The control relay's basic unit shown in Figure 3.12a consists of four contact blocks (poles) marked with reference numbers:

- 13-14 (NO contact)
- 21-22 (NC contact)
- 33-34 (NO contact)
- 43-44 (NO contact).

Reference numbers are also shown as a table in most control diagrams, usually below the relay's coil symbol (Figure 3.12c).

The manufacturer's stamp should be marked on the unit and reference letters marked adjacent to the terminals, as illustrated in Figure 3.13a (53*NO*, 61*NC*, 75*NC*, 87*NO*). These manufacturer's numbers are an important reference for reordering or cross ordering with other manufacturers' components (Figure 3.13b).

a)

b)

Figure 3.13 – Contact reference

The relay coil is marked in diagrams with a standard code: A1, A2. If the coil is designed to be energised with an alternating current, aluminum rings are crimped on to both ends of the magnetic core (seen adjacent to the magnetic core in Figure 3.14). This creates a small out-of-phase current, which increases the minimum pull on the armature during the AC cycle. If the noise from a magnetic system becomes louder while in operation, the position of the magnetic system shading rings should be inspected.

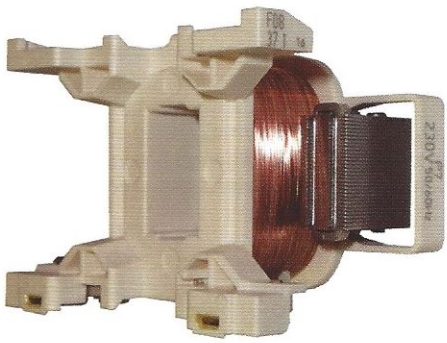


Figure 3.14 – Relay coil

3.4.1 Voltage Limiting Elements

Electronic equipment such as programmable logic controllers (PLCs), timing relays and coupling modules that can be affected by other components, are commonly used with conventional switching equipment. For example, disturbances can be created by inductive loads when relays' coils are switched on or off.

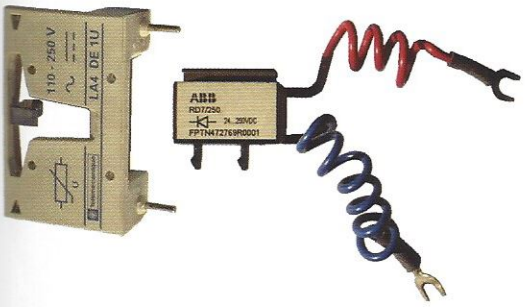


Figure 3.15 – Suppressor modules

To reduce the disturbance, coils can be connected to suppressor modules (Figure 3.15), also called surge protectors, which are connected across the coils and dissipate the energy from the collapsing magnetic field when switched off.

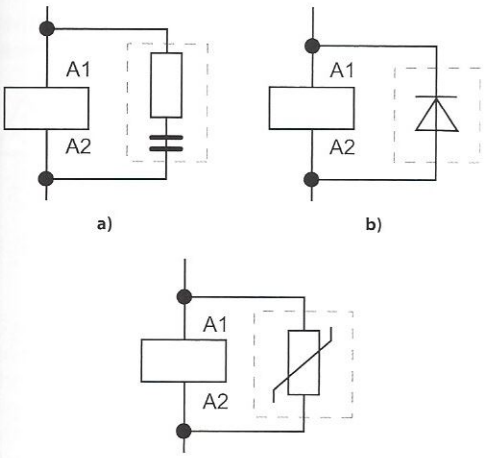


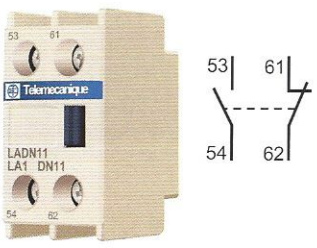
Figure 3.16 – Suppressor module symbols

Suppressor modules for relays and contactor coils include the following:

1. RC links - a resistor in series with a capacitor used with AC operated coils (Figure 3.16a)
2. diode elements - provide excellent voltage limitation and are used for DC operated coils (Figure 3.16b)
3. varistor elements - used for AC and DC operated contactors (Figure 3.16c) and achieve virtually unchanged switching times.

3.4.2 Top-Mounted Auxiliary Contact Modules

The modular system is formed around basic units, which are equipped with additional functions by means of modules. In addition to basic unit contacts, top-mounted auxiliary contact modules offer two (Figure 3.17a) or four (Figure 3.17b) contact extensions.



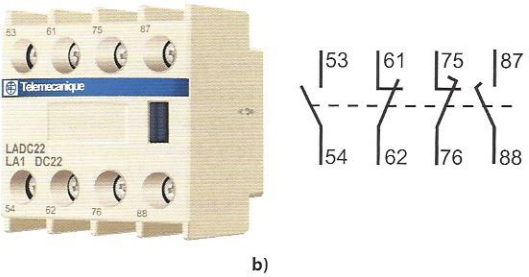
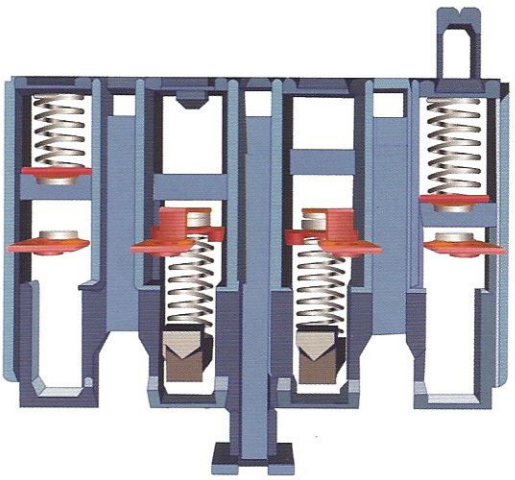


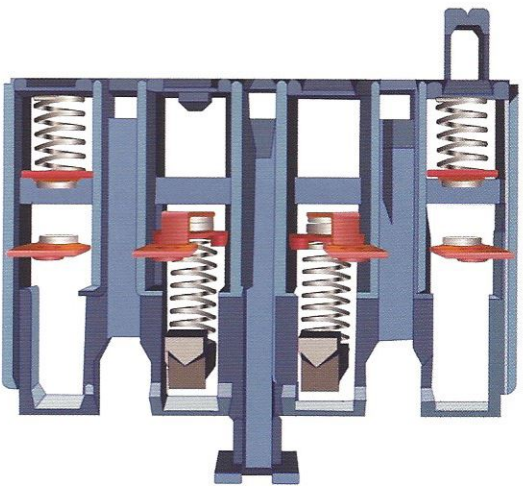
Figure 3.17 – Top-mounted auxiliary contact modules

To prevent duplicating terminal markings when NO and NC contacts are combined, the modules will have different position digits.

Figure 3.18 illustrates the difference between early make (EM) and late break (LB) contacts and make (NO) and break (NC) contacts that are met at top-mounted auxiliary contact modules. The contacts layout for the module illustrated in figure 3.18a is, *from left to right*: 53-54 NO, 61-62 NC, 75-76 NC/LB and 87-88 NO/EM. The contacts layout for the module illustrated in figure 3.18b is, from *left to right*: 53-54 NO, 61-62 NC, 71-72 NC and 83-84 NO.



a) Telemecanique LADC22 module with early make and late brake contacts



b) Telemecanique LADN22 module with instantaneous contacts

Figure 3.18 – Top-mounted auxiliary contacts modules' internal components outline

3.4.3 Ordering Relays

When preparing a spares order, the reference numbers or letters should not be ignored, particularly if the requested type of relay is not available from the supplier and another vendor is being asked for an alternative. To avoid mistakes it is suggested that the relay order form should include the following information:

- Relay manufacturer
- type of relay
- coil voltage
- number of contact blocks
- contact reference numbers or contact reference letters.

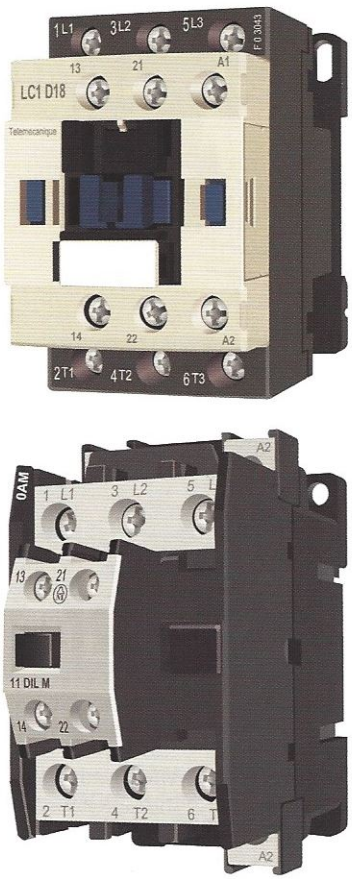
The relay order should be similar to the one shown in Table 3.1.

Nr.	Required quantity	Description
1	1pc	Relay, Telemecanique CAD32, coil 200 V AC, contacts: 3 × NO; 2 × NC; Top-mounted aux. contacts module, Telemecanique LAD C22;
2	1pc	Contacts: 1 × NO; 1 × NC; 1 × LB (75-76); 1 × EM (87-88);

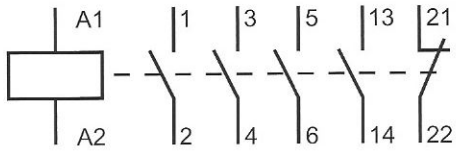
Table 3.1 – Relay order sample

3.5 Contactors

A contactor is used to switch larger amounts of electrical power through circuit contacts of 10 amps or higher (Figure 3.19).



a)



b)

Figure 3.19 – a) Contactors b) Diagram symbols

Contacts, carrying such a load are called 'Main Contacts' (Figure 3.20).These are always NO (normally open) contacts and designated by single digits in pairs: *1-2*, *3-4*, *5-6* (for three pole contactors) and *7-8* (for four pole contactors). In addition to reference numbers, the following reference letter code is used: *L1*, *L2*, *L3*. This is shown on the top of the contactor, representing three-phase power supply terminals and *T1*, *T2*, *T3*, from the bottom of the contactor, representing the load side terminals.

Figure 3.20 illustrates a contactor arrangement. The main contacts marked with (1) are movable, but the main contacts marked with (2) are fixed.

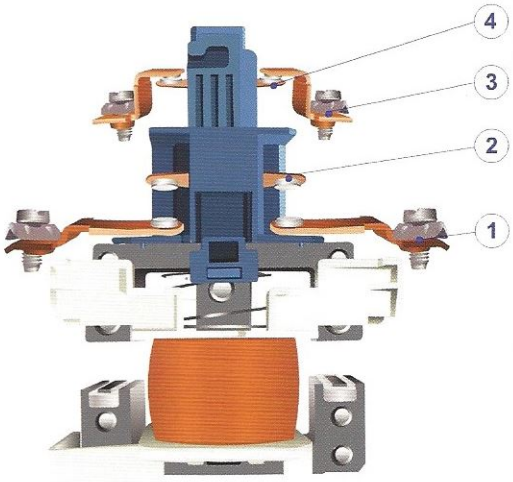
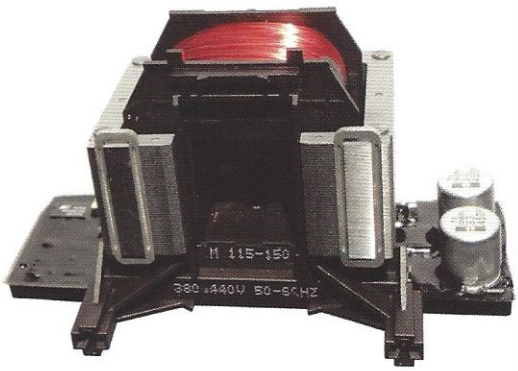


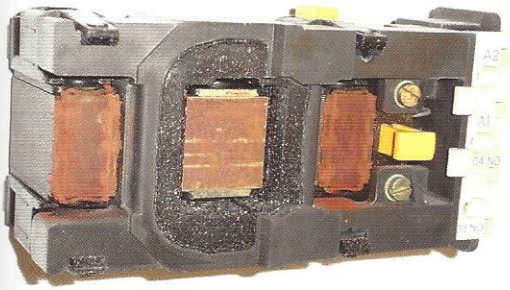
Figure 3.20 – Contactor arrangement

The auxiliary contacts, (3) fixed and (4) movable, are only used in control circuitry for monitoring purposes.

If the contactor coil is designed to be energised with AC (alternating current), aluminium or copper (shading) rings are crimped to both ends of the magnetic core (Figure 3.21a) creating an out-of-phase current that increases the minimum pull on the armature during the AC cycle.



a)



b)

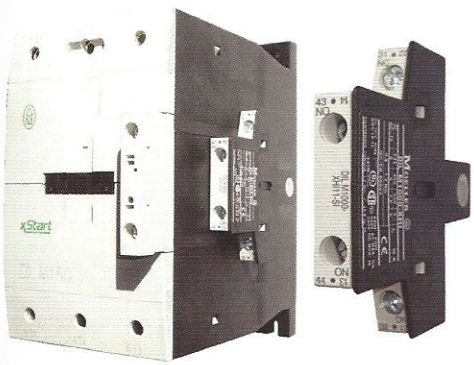
Figure 3.21 – Contactor magnetic systems:
a) 'Shading rings' crimped to magnetic core
b) Contaminated magnetic system

Modern contactors are extremely reliable but may have common faults. Worn main contacts due to the arc-effect is a known problem. The operating coil should be opened for internal inspection under recommended routine maintenance systems.

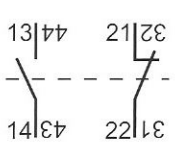
A high standard of maintenance on contactors is paramount to the efficient operation of a vessel. High standards of preventive maintenance will minimise ship inefficiency and related downtime.

3.5.1 Side-Mounted Auxiliary Contact Modules (Lateral contacts modules)

These are used as an accessory for large contactors and are connected through control circuits where they are used for monitoring purposes, see Figure 3.22a. Side-mounted contact reference numbers, representing NO and NC contacts, are defined as previously explained. Two position numbers adjacent to each contact terminal, Figure 3.22b, show that modules can be from either side of the contactor. This means that one of the two numbers is the right way up while the other is upside-down.



a)



b)

Figure 3.22 – a) Contactor side-mounted contact modules
b) Side contact reference numbers

3.5.2 Mechanical Interlock, Mechanical-Electrical Interlock

The mechanical interlock in Figure 3.23 is assembled between two contactors to prevent them simultaneously closing and is often used as an added safety feature to electrically interlocked contactors. Even with a mechanical force against the magnetic system, the contacts of both contactors cannot close simultaneously.

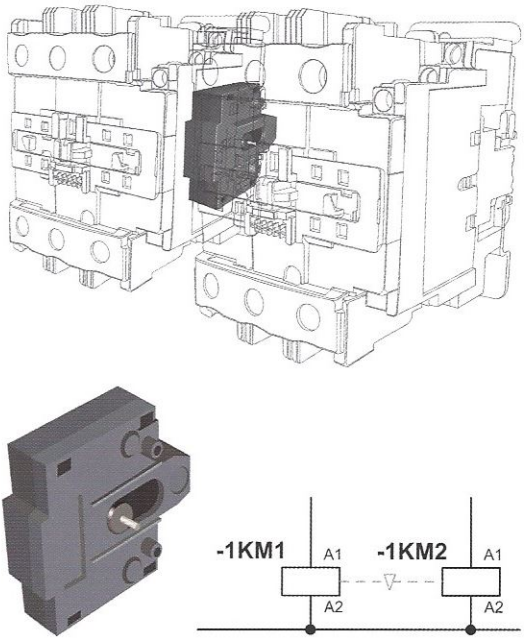


Figure 3.23 – Mechanical interlock and mechanical interlock symbol

An electrical interlock consists of two interlinked auxiliary NC contacts. While one contactor (eg 1KM1) is energising, its interlocking contact (1KM1/21-22) opens, preventing current flow. During this time current flows through the coil of the second contactor (1KM2).

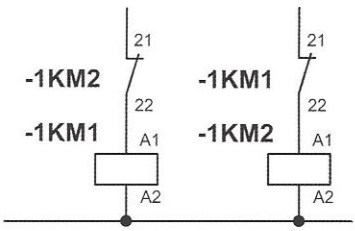


Figure 3.24 – Electrical interlock

3.5.3 Mechanical Latch

Manufacturers supply mechanical latching modules that should be fitted with either control relays or contactors. The resulting devices are called mechanically held relays, shown in Figure 3.25.

Once the closing impulse has been given to the coil (A1-A2), the mechanical latch holds the contactor or the control relay in the closed position without the coil being continually energised. Interruption of the contactor takes place through a further impulse, which releases the latch, NO (normally open) trip. The latch reset coil terminals are assigned with the letter *'E' (E1-E2)*.

Figure 3.25 – Latching module

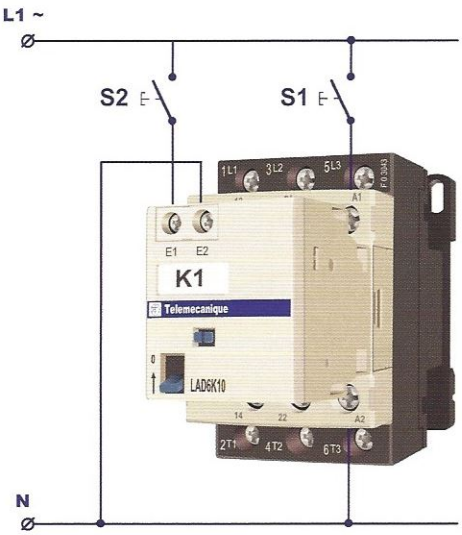


Figure 3.25a – Latching module operation principle

3.5.4 Pneumatic Timer Modules

Contactors and relays from certain manufacturers are constructed to work with a separately top-mounted 'shock absorber' mechanism, Figure 3.26. It is attached as an accessory to the basic unit, preventing immediate full motion of the contacts when the coil is either energised or de-energised.

This addition provides the ordinary relay with time-delay actuation. Time-delay modules are constructed to delay armature motion on coil energisation, de-energisation or both. A relay with such an accessory becomes a timer and is illustrated with a timer symbol.

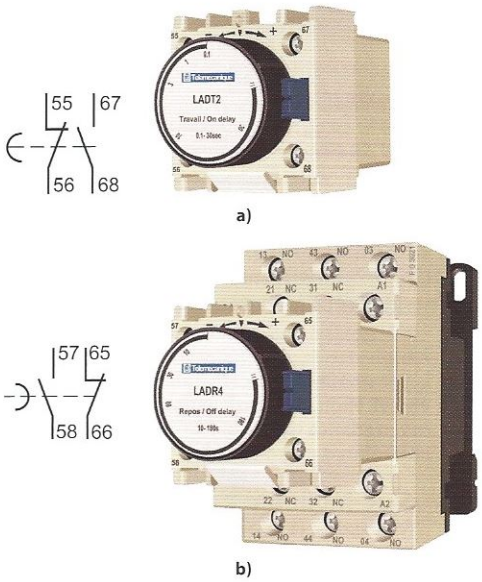
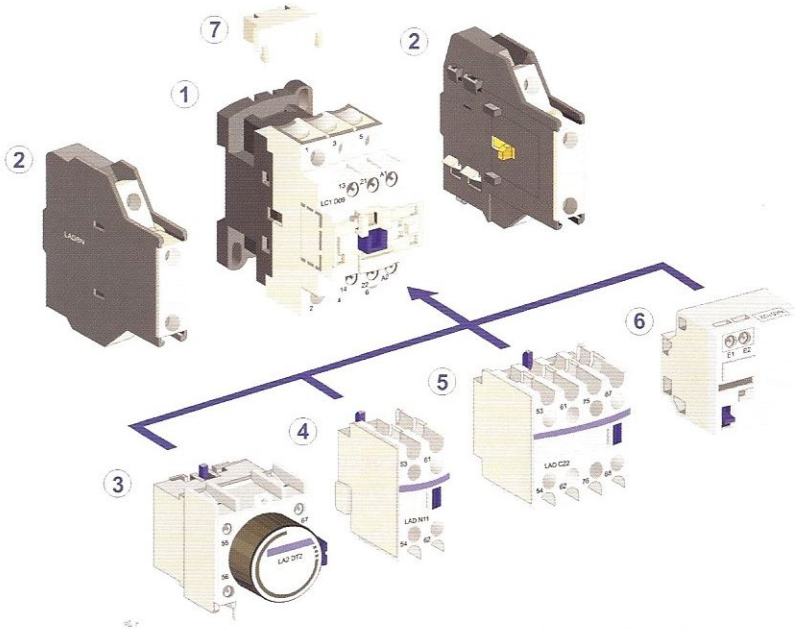


Figure 3.26 – a) Timer module Telemecanique LA2 DT2 On-delay b) Timer module Telemecanique LADR4 Off-delay fitted with control relay

3.5.5 Contactor Accessory Overview

The itemised overview of contactor accessories, illustrated in Figure 3.27, should help while sending routine technical inspection spare orders or when ordering relays or contactors in an emergency.



1. Basic unit
2. Side-mounted (lateral) auxiliary contact module
3. Pneumatic time module (On- and Off-delay), top-mounted
4. Two pole top-mounted auxiliary contact module
5. Four pole top-mounted auxiliary contact module
6. Mechanical latching module
7. Surge protector

Figure 3.27 – Telemecanique TeSys d-Contactor accessory

4 Overload Relays

4.1 Introduction

Overcurrent is an excessive current that is caused by an overload, short circuit or ground fault. Under normal operating conditions insulation separates the conductors and prevents current flow, but if damaged there can be a short circuit.

When a short circuit occurs, the conductors touch, resistance drops to almost zero causing a rapid increase in current. The heat generated may damage any equipment that is connected, unless there is a safety device such as a circuit-breaker or fuse.

In contrast, an overload has a much lower current than a short circuit.

An overload may result when there are too many devices connected to a circuit or if electrical equipment is forced to exceed its rated parameters. An overload is a lower current than a short circuit, a short-lasting overload may not require the circuit to be shut-down. For example, when a motor is started, the starting current is five to seven times the nominal current for a short period of time. Because of this, there must be overload protection for the motor using a separate device known as an overload relay.

Overload relays, also known as overcurrent relays, are designed to meet the special protective needs of motor control circuits and are used to protect motors from overheating (Figure 4.1a). They are referred to in diagrams with the letter **–F** (Figure 4.1b), and can be either directly mounted as illustrated in Figure 4.1c or separately mounted.

If an excessive current is drawn for a pre-determined amount of time, the relay will open the auxiliary contact *95-96,* which is connected in series through control and safety circuitry and as a result, the motor will be disconnected from the power source.

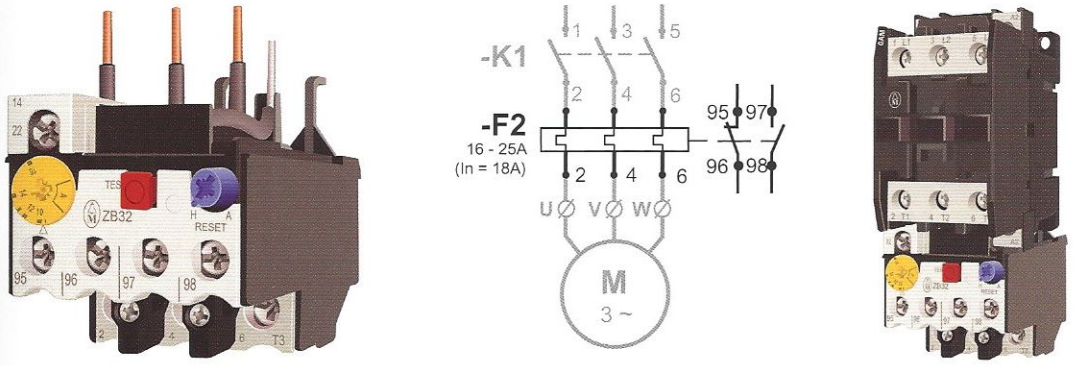
If the relay tripped holding on its contacts latched, the cause of the overload should be solved before resetting the starter.

The overload relay dial should be set to the name plate Full Load Current (FL), within 1.0 to 1.15 times the FL. A relay set too low will prevent the motor being used, set too high it will not guarantee full overload protection.

4.2 Bimetal Overload Relays

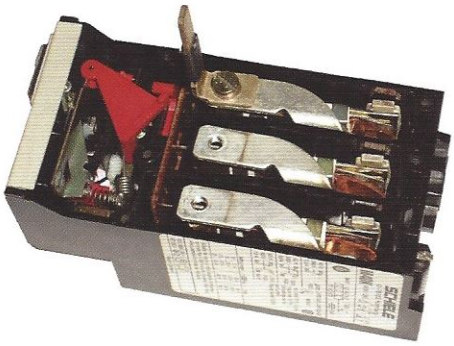
A motor starter's overload protection can be accomplished by using a bimetal overload relay, illustrated in Figure 4.2a. This component consists of a small heater element wired in series with each phase of the motor power circuitry. A bimetallic strip can be used as a trip lever, as seen in Figure 4.2b. The bimetallic strip is made of two dissimilar metals bonded together. The varying thermal expansion characteristics cause the strip to bend at a preset rate when heated.

In an overload situation, the current through the motor's windings increases and the heat will also rise. Under normal operating conditions, while the motor's nominal current flows through, heat generated by the heater element will be insufficient to cause the bimetallic strip to bend enough to trip the overload relay. In an overload condition, heat generated will cause the bimetallic strip to bend until the mechanism is tripped and 95-96 contacts are opened, stopping the motor from further damage.

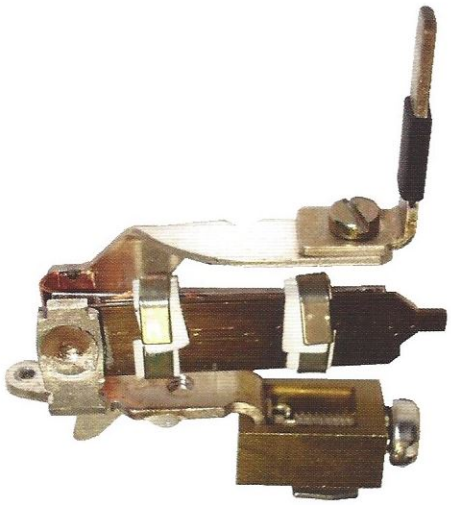


a) b) c)

Figure 4.1 – Overload relay



a)



b)

Figure 4.2 – a) Shiele M40K overload relay (shown with open casing)
b) Thermo-element overview

Destruction of relay's thermo elements would take place only in the event of a short circuit on the load side of the relay when the back-up fuse is rated too high.

In most cases, this will also endanger the attached contactor and/or motor.

Some overload relays equipped with a bimetallic strip are designed to reset the circuit automatically.

The hand reset position, illustrated in Figure 4.3, should always be used where continuous contact devices are used, eg pressure and level switches, to prevent automatic restarting.

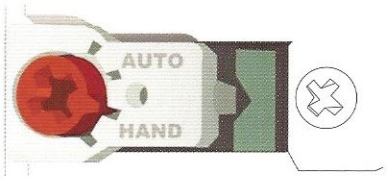


Figure 4.3 – Hand reset position

4.3 Trip Class

Overload relays are rated by a trip class, which defines the length of time in seconds it takes for the overload relay to trip at a specific current. This is typically six times the continuous current rating. The most common trip classes are 5, 10, 20 and 30. They determine different tripping characteristics for various starting conditions of motors, from normal starting to heavy starting.

For example, a Class 10 overload relay has to trip the motor off-line in 10 seconds or less after an overload condition occurs (for the currents 5 times of a full load current).

This is usually sufficient time for the motor to reach its full speed.

4.4 Current Transformers' Operated Overload Relay (Electronic Overload Relays)

For particularly high-inertia motors where the tripping delay is shorter than the run up time, adjusting the overload relay may solve the starting problem, but the motor would no longer be adequately protected during normal operation and as a rule, this should not be done.

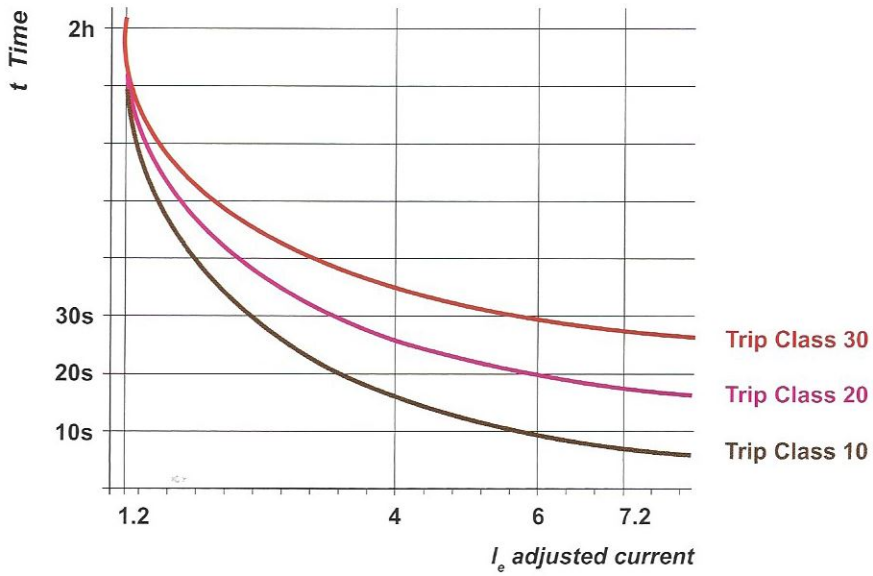


Figure 4.4 – Overload relay trip class characteristic

Another option for motor protection are electronic overload relays, as seen in Figure 4.5a, which are used for medium and large motors. They consist of three inbuilt, special, saturable core current transformers, illustrated in Figure 4.5b, and an incorporated electronic circuit.

An electronic overcurrent relay usually converts the measured current into a voltage by rectifying the line current into a DC voltage that is proportional to the inline current. This is compared to a set voltage level within the monitoring unit. The tripping time delay is the time it takes to charge the inbuilt capacitor.

Electronic overload relays also offer phase loss protection (this does not exist in bimetallic overload relays). During the start up of a large motor, if one phase is lost the motor windings are far more susceptible to overheating. When this occurs the electronic overload relay will very quickly detect the phase loss and disconnect the motor from the power source.

The features and benefits of electronic overload relays vary, but there are a few common traits. One advantage offered by electronic overload relays is a heaterless design, which allows the electronic relay to be insensitive to the ambient temperature, minimising nuisance tripping.

4.5 Breakdowns Noted for Electronic Overload Relays

Reliable, long-life devices, such as electronic overload relays, may still have breakdowns that are usually due to neglected maintenance. Figure 4.6 illustrates the internal core of a broken transformer. Modern thermographic surveys would help to prevent this type of breakdown.

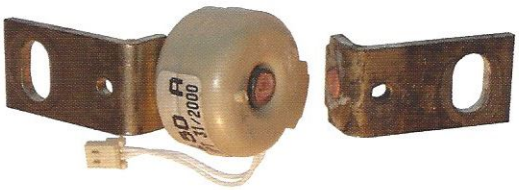
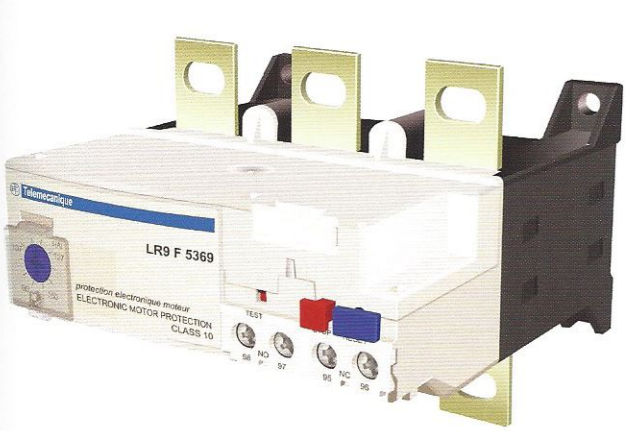
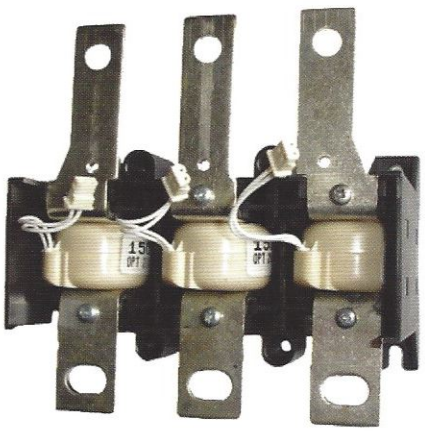


Figure 4.6 – Broken core of a current transformer



a)



b)

Figure 4.5 – a) Telemecanique LR9 D electronic overcurrent relay

b) Overview at current transformers

Motor Starter Protectors, Motor Protective Miniature Circuit-Breakers

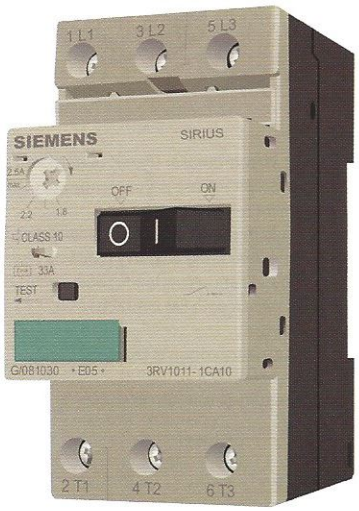
5

5 Motor Starter Protectors, Motor Protective Miniature Circuit-Breakers

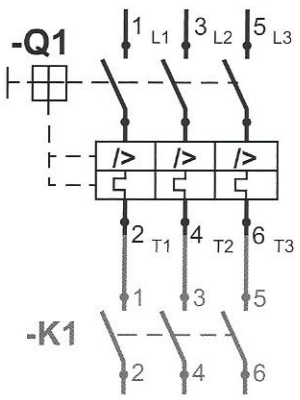
5.1 Introduction

Motor Starter Protectors (MSPs), also called Motor Circuit-Breakers (MCBs), incorporate either a class 10 or 20 bimetallic overload relay and magnetic trip elements for short circuit protection, providing overload, short-circuit and single-phase protection for smaller three-phase motors (see chapter 9).

MCBs (Figure 5.1) operate on the current-limiting principle. If there is a short-circuit the contacts will open electro-dynamically by the short-circuit current.



a)

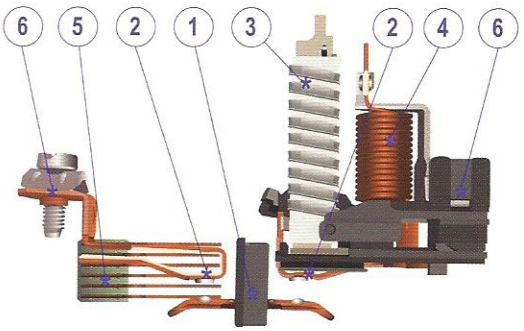


b)

Figure 5.1 – Siemens Motor Starter Protector
a) Basic unit
b) MSP's symbol

MSPs are referred to in Figure 5.1b by the letter **–Q**. They are available in a variety of enclosures and assembled with contactors by mounted rail adaptors or link-modules.

Figure 5.2 illustrates the typical parts of MSPs:



1. Movable contact assembly
2. Fixed contacts assembly
3. Thermal overload release
4. Instantaneous magnetic release
5. Arc reducing chute with arc splitting plates
6. Terminals.

Figure 5.2 – MSP release outline

The thermal trip action is achieved by using a bimetallic element which is heated by the load current.

Short circuit action is achieved using an instantaneous magnetic release. When a fault occurs, the short circuit current causes the electromagnet to attract an armature which unlatches the trip mechanism, tripping all three poles of the breaker. This action occurs very quickly, the only delay is the time it takes for the contacts to physically open and extinguish the arc, approximately 20 ms.

Figure 5.1b illustrates two releases which are incorporated in MSPs.

Magnetic overcurrent release

Thermal Overload release

The instantaneous magnetic overcurrent and thermal overload releases trip all three poles of the breaker in a three-phase system. This tripping cannot be prevented by forcing the latch position as the breakers have a trip-free mechanism.

Once the fault that caused the short-circuit is eliminated, the limiter must be reset by hand before the circuit-breaker can be switched on again.

The MSP can be connected in parallel to the fuses. If one fuse blows, the breaker is activated by the release sending a trip signal through the auxiliary contacts to the motor control device to switch the motor off. The motor is then not subjected to single phasing and costly motor burnouts are avoided.

5.2 MSP Accessories

If necessary, MSPs can have auxiliary contacts, trip indicating contacts and undervoltage release or shunt release as an accessory.

When the condition of an MSP's main contacts, either closed or open or an MSP's protection is to be monitored, eg by an alarm system, an NO-NC side-mounted auxiliary block, as illustrated in Figure 5.3a, 5.3b and 5.4a, is used.

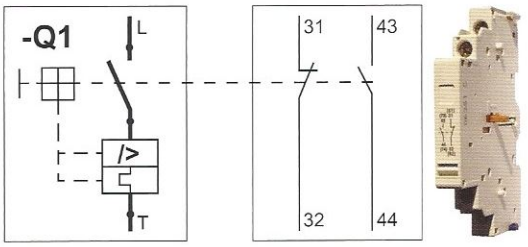


Figure 5.3 – MSP standard auxiliary contact block

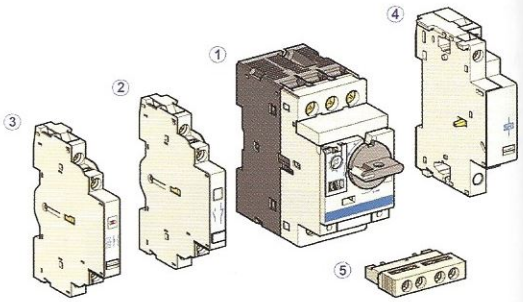
A side-mounted Early Make (EM) auxiliary contact block, Figure 5.4b and c, might also be a feature of control diagrams. The working principle of these EM contacts is similar to relay EM contacts.

5.2.1 Undervoltage Release

An undervoltage release block assembled with an MSP, see Figure 5.5 unit 4, allows the breaker to be remotely controlled by tripping the mechanism if there is a significant drop in the power supply voltage. This can stop a motor restarting automatically and unless the release is re-energised, it is impossible to close the circuit-breaker, either mechanically or electrically.

Undervoltage releases are used through various interlocking and safety circuits, for example motor starter safety devices, protection and monitoring relays and safety stop buttons.

Figure 5.5 illustrates the Telemecanique MSP TeSys series accessories.



1. Motor protective circuit-breaker (Rated operational current up to 25A, Short circuit release permanently set to 14 x *I*u, Adjustable overload release 0.6 – 1 x *I*u)
2. Side-mounted auxiliary (lateral) contacts block (NO, NC)
3. Side-mounted trip indicating auxiliary contacts block (Differential fault indication overload-/short-circuit trip; On/Off for starter combination with EM contacts)
4. Undervoltage release
5. Front-mounted auxiliary contacts block (NO, NC).

Figure 5.5 – Telemecanique miniature circuit-breakers accessory overview

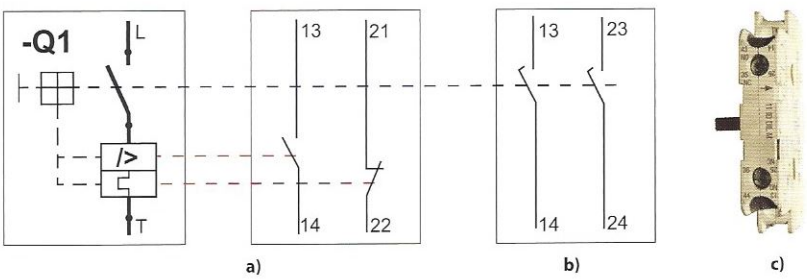


Figure 5.4 – a) Trip-monitoring NO, NC auxiliary contacts
b) Latch monitoring EM aux. block
c) Kl.Moeller 11ID DILM NO, LB aux.block

Rotary Switches, Selector Switches and Changeover Switches

6

6 Rotary Switches, Selector Switches and Changeover Switches

6.1 Introduction

Rotary selector switches are used for the control of power circuits to connect and disconnect relays, instrumentation and remote equipment. The number of possible switch combinations is virtually unlimited.

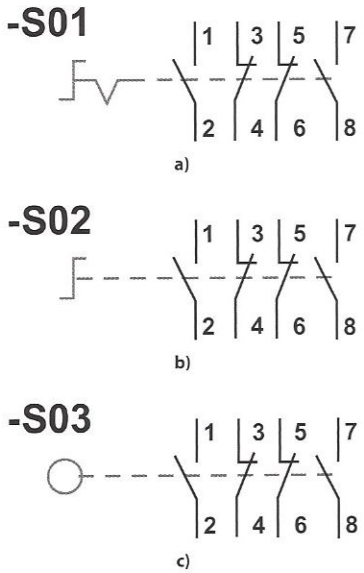


Figure 6.1 – Types of selector switches
a) maintained b) spring return c) key operated

Typical applications for rotary switches and switch disconnectors include:

- Maintenance, repair and safety switches
- on/off switches
- main switches
- control switches
- manual/automatic switches.

6.2 Selector Switches

Selector switch contacts are often coded either with pairs of digits, eg 1-2, 3-4, 5-6, 7-8, or occasionally with function digits similar to those used for relay contacts (Chapter 3.1 Contact symbols and terminal markings).

When a particular rotary selector switch is used for a certain appliance, a contact reference system, also known as a flow chart, should be used to understand a contact's commutation sequence. The reference system illustrated in Figure 6.2a and b provides an overview of how to interpret flow charts.

Each cell from a given table, as seen in Figure 6.2a and b, represents a contact status. The number of cells depends on the number of contact groups the selector switch has. The cell symbol ☒ illustrates a status change event determining whether the transition is from open-to-closed or vice versa. The vertical digits on the left of the table represent the transition steps.

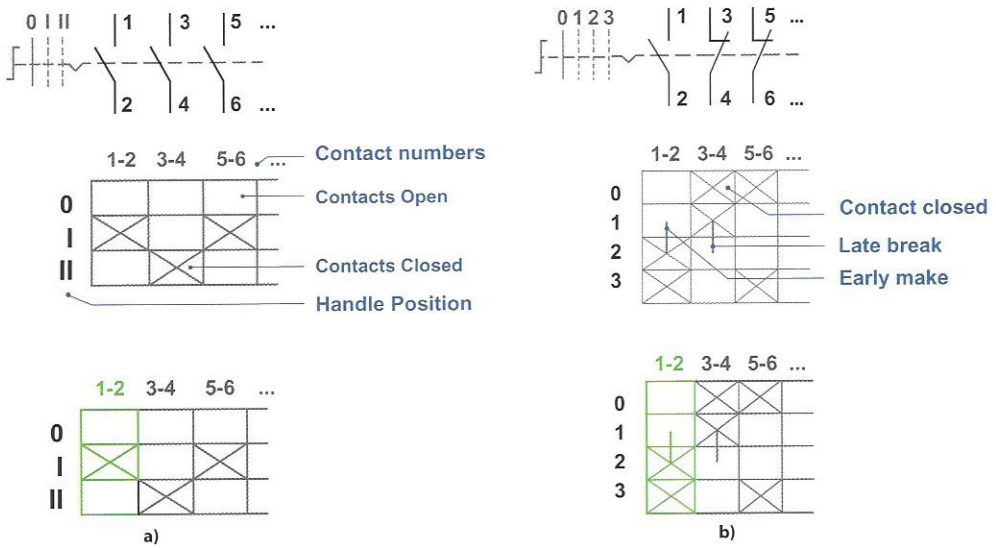
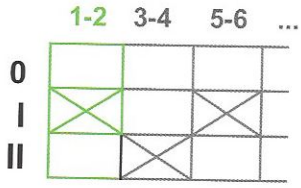


Figure 6.2 – Selector switch contact reference system

Assuming that the flow chart in Figure 6.2a is interpreted first:

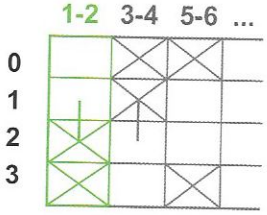


- Neutral position for the selector switch is -0-. All contacts represented through the diagram (1-2, 3-4, 5-6, ...) are related to this particular position. All shown contacts are open
- shifting the selector switch handle from position -0- to position -I-, the status change symbol ⊠ appears in the cell below the tag of contact 1-2, changing its position to closed unless the handle is moved
- shifting the handle further, from position -I- to position -II-, the status change symbol disappears, contact 1-2 opens and remains opened unless the handle is moved away from position -II-.

Other contact status (3-4; 5-6; ...) should be read in a similar manner.

The flow chart in Figure 6.2b has a line adjacent to the status change symbol ⊠ representing either a delayed- or early-transition for the contact group. This depends on the direction of the line and which position you intend to move the switch, ie 0-1-2-3 or 3-2-1-0.

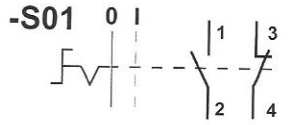
The flow chart in Figure 6.2b shows that:



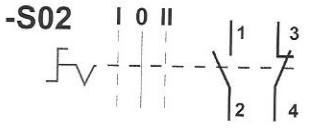
- Moving the selector switch handle from position -0- to position -1-, the status of contact 1-2 does not alter because no status-change symbol exists on its row
- moving the selector switch handle further, from position -1- to -2-, the status change symbol has an incoming line representing an early make function, this indicates that contact 1-2 will close earlier than the others
- on shifting the switch further, from position -2- to -3-, contact 1-2 will remain closed
- on returning the switch one step back, from position -3- to -2-, contact 1-2 remains closed
- if continuing to switch from position -2- to -1-, closed contact 1-2 shows a line leading out of the status change cell, indicating that contact 1-2 will work as a 'late break' contact.

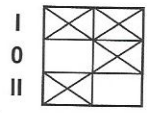
6.3 Diagram Symbols

If an employed selector switch is not a regular toggle On-Off switch (Figure 6.3a), flow charts will be required for troubleshooting. Figure 6.3b represents a flow chart for a 3-position rotary selector switch (I-Hand, 0-Off, II-Automatic), Figure 6.3c shows a 4-mode selector switch with a common changeover contact. The common contact selector switch is always represented in position 0 unless specific remarks are made. The number of available transitions (0-1-2-3), shown beside the handle, determine the positions that certain contacts would turn over by common contact, Figure 6.3d.

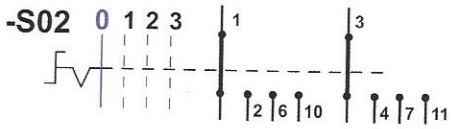


a)



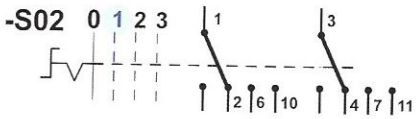


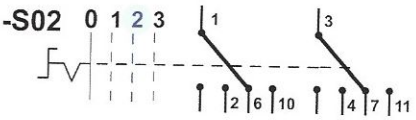
b)

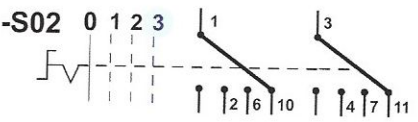


0 - off
1 - local
2 - hand
3 - standby

c)

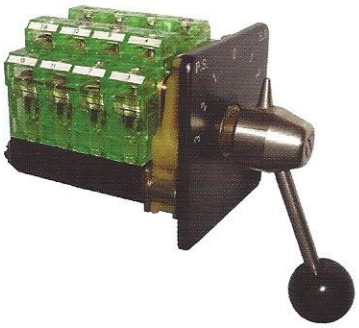




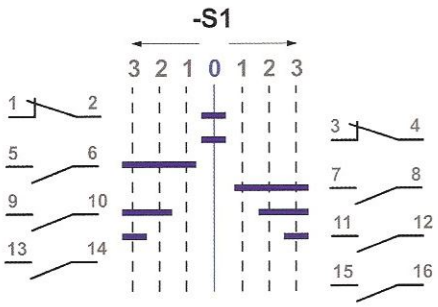


d)

Figure 6.3 – Rotary selector switches. Diagram variations



a)



b)

Figure 6.4 – a) Spohn & Burkhardt selector switch used for bow thruster Bakker application and b) contact reference table

Figure 6.4 illustrates a 3-step controller selector switch and its flow chart which has been installed by BAKKER as a bow thruster control.

The contacts are depicted in their de-energised condition for the **0**-position.

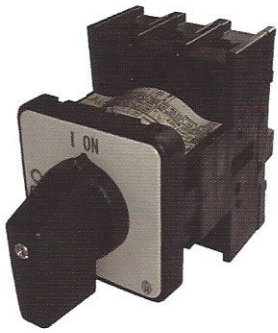
When switching from the -**0**- position to the port or starboard side, the contacts will change status in each instance as follows:

Position **1** port: 1-2 opens, 3-4 opens, 5-6 closes, others maintain condition
Position **2** port: 1-2 remains open, 3-4 remains open, 5-6 remains closed, 9-10 closes
Position **3** port: 1-2 remains open, 3-4 remains open, 5-6 remains closed, 9-10 remains closed, 11-12 closes

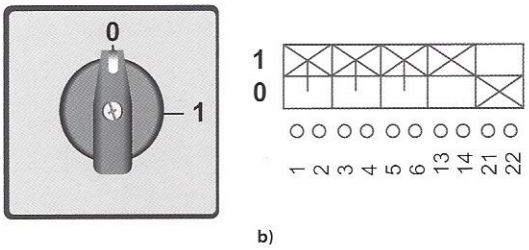
Position **1** starboard: 1-2 opens, 3-4 opens, 7-8 closes, others maintain condition
Position **2** starboard: 1-2 remains open, 3-4 remains open, 7-8 remains closed, 9-10 closes
Position **3** starboard: 1-2 remains open, 3-4 remains open, 7-8 remains closed, 9-10 remains closed, 11-12 closes.

6.4 Rotary Switch

Rotary switches vary according to their purpose and manufacturer. Below are three different switches with flow charts indicating the contact positions and function.



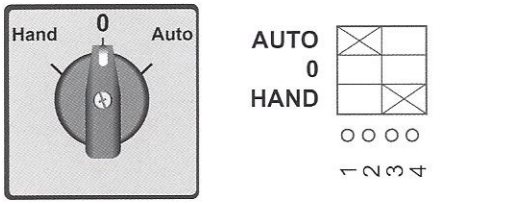
a)



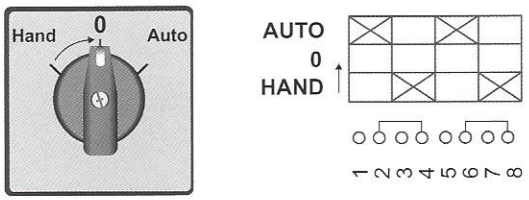
b)

Figure 6.5 – Main switch with 3 main EM contacts, NO and NC aux. block

Changeover switches



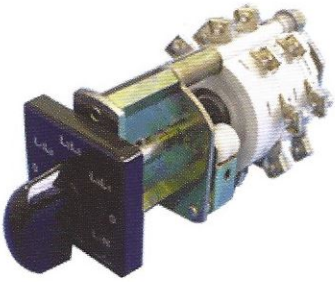
a)

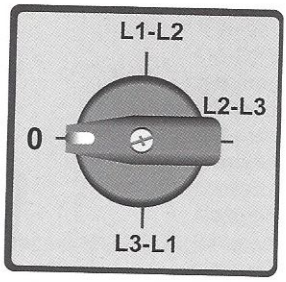


b)

Figure 6.6 – a) Hand/auto selector switch with -0- position
b) Hand/auto selector switch with spring return to -0- from hand position

Instrument control rotary switches





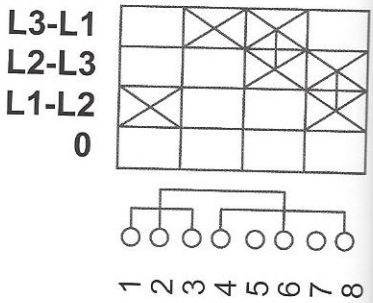


Figure 6.7 – Three-phase voltmeter instrument switch

Timer Relays and Multifunctional Timer Relays 7

7 Timer Relays and Multifunctional Timer Relays

7.1 Introduction

Timer relays and solid state timers are used for various automation appliances and have many timer functions or modes of operation. When troubleshooting, it is important to understand what initiates the time delay when the time sequence starts and when the output relay activates.

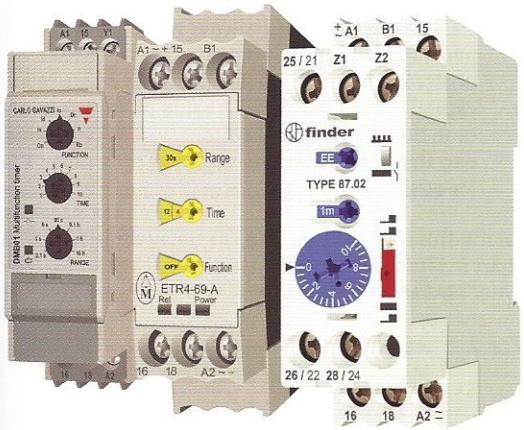


Figure 7.1 – Timer relays

Timer relay CO contacts are identified as either normally open or normally closed and adjacent umbrella symbol shows the direction the time delay operates, ie on relay's energizing or on de-energizing.

The following is a description of the four basic types of time-dependant operated contacts:

- Normally open, timed closed (NOTC) contact Figure 7.2 a
- Normally open, timed open (NOTO) contact Figure 7.2 b
- Normally closed, timed open (NCTO) contact Figure 7.2 c
- Normally closed, timed closed (NCTC) contact Figure 7.2 d.

Normally open, timed closed (NOTC) contact Figure 7.2a
The NOTC contact, (coded in diagrams as function digits 15-18), is normally open when the relay is de-energised. The contact is closed by applying power to the relay terminals A1-A2, but only after the relay has been continuously powered for the specified amount of time. In other words, the direction of the contact motion is identical to a regular NO contact, but there is a delay in the closing direction when the relay energises. This type of contact is also known as a normally open on-delay.

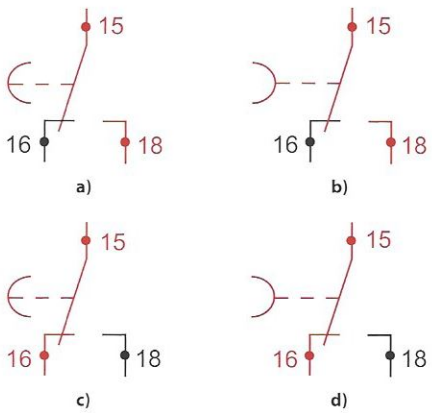


Figure 7.2 – Basic types of time-dependent relay contacts

Normally open, timed open (NOTO) contact Figure 7.2b
Similar to the NOTC contact, the NOTO contact is coded in diagrams as function digits 15-18 as it is normally open when the relay is de-energised, but closed without a time delay. The timing action occurs on de-energisation of the relay, ie delaying the opening. This type of contact is also known as a normally open off-delay.

Normally closed, timed open (NCTO) contact Figure 7.2c
Coded in diagrams as function digits 15-16, an NCTO contact is normally closed when de-energised and opened once the relay has been continuously powered for the specified amount of time. The direction of the contact motion is identical to a regular NC contact, but there is a delay when opening. This type of contact is sometimes known as a normally closed on-delay.

Normally closed, timed closed (NCTC) contact Figure 7.2d
Similar to the NCTO contact, an NCTC contact coded in diagrams as function digits 15-16, is normally closed when the relay is de-energised. However, the time delay occurs when the relay is de-energised, it is sometimes known as a normally closed off-delay.

Timer relay manufacturers incorporate resistor-capacitor (RC) networks in circuits to produce time delays. Advanced timer features can include 'one-shot' which produces an output pulse for each transition from de-energised to energised, or 'recycle' which repeatedly produces an on/off output while energised. Others are managed either by a single function time relay, Delay on Make, Delay on Break, One-shot Timer, Interval Timer, Recycle Timer, shown as a flash timer in Figure 7.3b. Multifunction timers have two independent internal relays, Figure 7.3c, allowing each changeover contact group to operate independently.

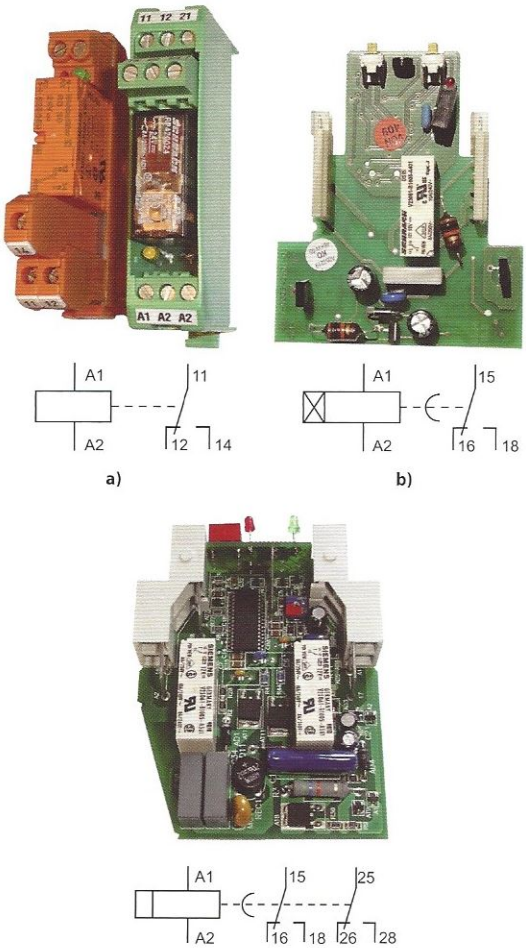


Figure 7.3 – a) Relay contacts coding: Miniature relays changeover contacts b) Single function multi-range time relay c) Multifunction timer relay

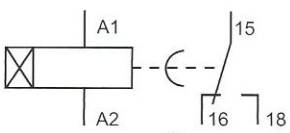
Unlike the changeover contacts of miniature relays marked with reference numbers 11-12-14, as seen in Figure 7.3a, timer relay contacts are marked in diagrams with relative reference numbers 15-16-18, 25-26-28 for a second CO contact group, as illustrated in Figure 7.3c. The 'Window' on the left of the coil's symbol and the 'umbrella' sign adjacent to the contact's symbol indicate the timer function.

7.2 Timer Relay Functions and Settings

7.2.1 On-Delay Timer

An On-delay timer, illustrated in Figure 7.4a, can also be called Delay on Make, Delay on Operate, Operate Delay, Prepurge Delay and Delay on Energisation.

Function charts which are provided by all makers are intended to explain the operating principles.



a)

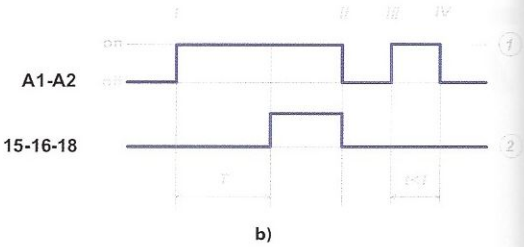


Figure 7.4 – Diagram symbol and On-delay function chart

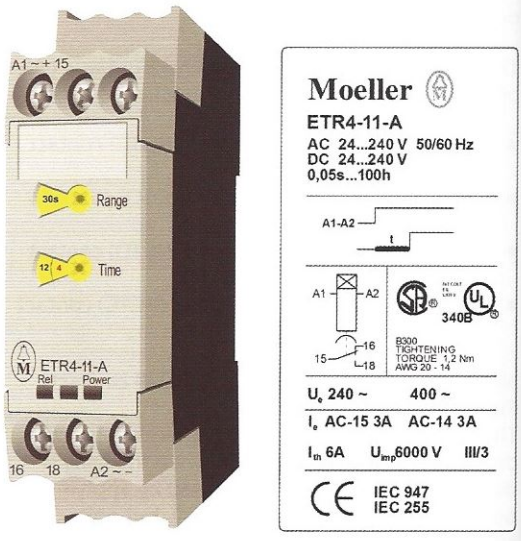
In Figure 7.4b:

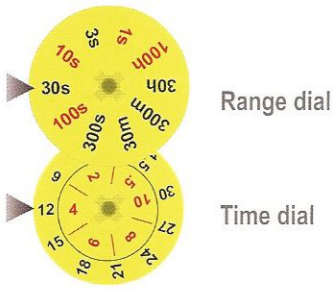
- The upper line (*1*) represents a power supply across the A1-A2 timer terminals. The lower stage is marked as *off*. The Step up line (*I*) means the power supply is applied (marked as *on*). The Step down line (*II*) means the power supply is removed
- the lower line (*2*) represents the contact status, this changes in respect of the power-line (*1*). The contact status always begins with a neutral configuration of contacts, 15-16 are normally closed, 15-18 are normally open
- capital letter *T* illustrates a value of adjusted time delay, while small letter *t* introduces a time gap that is less than the adjusted time delay *T* (in other words, t<T).

Taking this into account, the On-delay timer function chart in Figure 7.4b can be studied to define the timer operation principle.

7.2.2 Range and Time Settings for Multi-ranged Time Relays

Time delay adjustment for multi-ranged time relays, Figure 7.5, depends on the set up of Range and Time rotary scale values. These vary among manufacturers. Range and Time rotary scale values are often colour coded, Figure 7.5c illustrates black and red colour code used for Kl.Moeller timers.





c)

Figure 7.5 – a) Kl.Moeller ETR4-11-A multi-range time relay b) Relay data sticker c) Range- and Time-dial

The time delay is set by the timer rotary switch, as seen in Figure 7.6. The Range must be set first. The appropriate range for the desired time delay should be set. The colour of the range scale chosen dictates the colour of the time scale used, ie a red range value refers to the red time rotary scale and a black range value to the black time rotary scale.

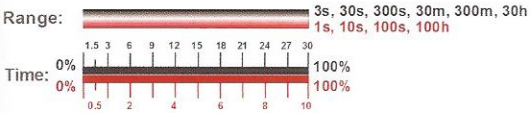


Figure 7.6 – The ratio between range and time sectors for Kl.Moeller ETR time relays

The examples in Figures 7.7 and 7.8 explain the procedure for two time delays to be set up: 6 seconds and 2 hours.

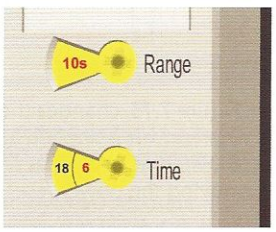


Figure 7.7 – Setting the 6 seconds delay

The range is set to 10s. The complete time scale sector (red) shown in Figure 7.6 equals 100% of the chosen range value. So, setting the time rotary scale, step-value should be calculated as:

'Range value' / 'max value of red-coded time sector' = 10s/10 = 1s

As the 10s range is used the 'time' digits become defined in seconds, from 0.5s to 10s, so a value of 6 equals 6s.

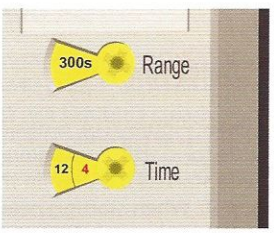


Figure 7.8 – Setting 2 hours (120 min) delay

The range scale is set to 300 minutes (black range scale). The time scale values are proportional to the 300 m range scale, so setting the time rotary scale, step-value should be calculated as:

'Range value' / 'max value of black-coded time sector' = 300 min/30 = 10 minutes.

As the 300 min range is used, the 'time' scale digits become defined values of 10 minutes (from 1.5 to 30), so a value of 12 equals 120 minutes (12 × 10).

7.2.3 Off-Delay Timers

Off-Delay Timers, as the name implies, delay the 'switching off' of the contact. Variations in the names may include: Release delay timer, Delay on Release, Postpurge delay and Delay on de-energisation.

There are three major types of off-delay timer:

- True-off timer
- off-delay timer operated with an initiate switch
- off-delay timer operated with an initiate loop.

To understand the difference, all three flow charts should to be studied.

True off timer (Figure 7.9)
This is the type used when the time gap is achieved by discharging a capacitor through an adjusted load. Load refers to the operating coil of an inbuilt miniature relay. When the supply voltage is applied at terminals A1-A2, the contacts will immediately changeover. However, when the supply voltage is removed the contacts will not change their status until the adjusted time delay elapses.

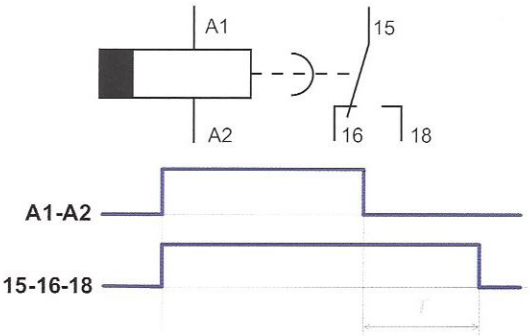


Figure 7.9 – True off timer

OFF-delay timer operated with initiate switch
Before studying the function chart in Figure 7.10, it is important to be aware that another status-line (*3*) is added between the power-line *1* and the contact-status line *2*. This line is called the initiate switch status line and is assigned with reference *B1*. It defines the status for the additional signal, a potential that is equal to the supply voltage, applied at the A1 terminal.

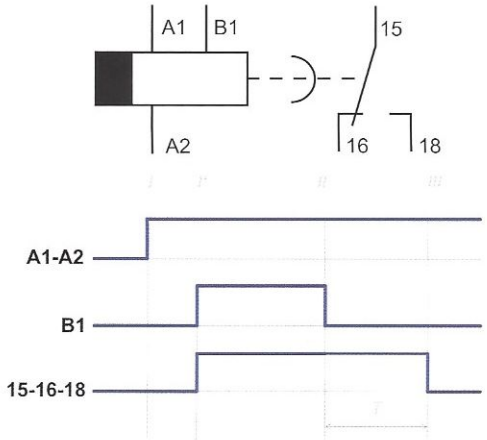


Figure 7.10 – Off timer initiated with B1 signal

The timer operates by applying a supply voltage across A1-A2 terminals (*I*) and the relay contact state remains neutral (15-16 closed). The contact status changes only when additional voltage is applied at the initiate terminal *B1*, *I'*: 15-16 opens, 15-18 close. The status remains unchanged until the voltage is removed from B1 and the timer's preset time delay *T* elapses (*II* - *III*).

OFF-delay timer operated with initiate loop

The difference between this timer and an off-delay timer operated with an initiate switch is that there is a loop between terminals Y1 and Z2. Closing the loop with an external control circuit initiates the off function in a similar way as the timer with an initiate signal, illustrated in Figure 7.11.

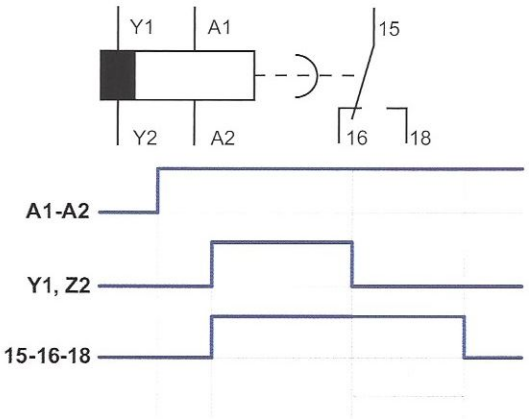


Figure 7.11 – Off timer operated with an initiate loop between Y1, Z2

7.2.4 Interval Timer

An interval timer, Figure 7.12, changes the contact status when power is applied at A1-A2 and this position is maintained until the time delay (*T*) elapses. The contacts then return to the neutral state, 15-16 closed. If the power is removed the time delay and output is reset.

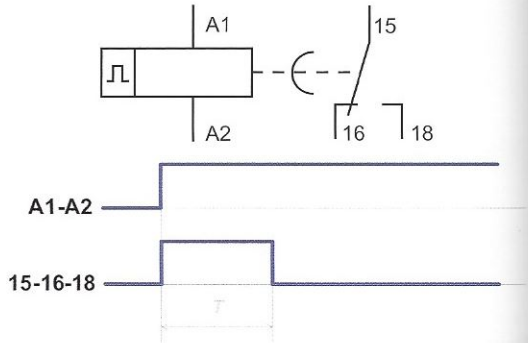


Figure 7.12 – Interval timer on-delayed

Interval timers may also be called Interval On, On Interval, Pulse Shaping, Bypass Timer Interval Delay and Delay on Energisation with Instantaneous Transfer.

7.2.5 Recycle Timer

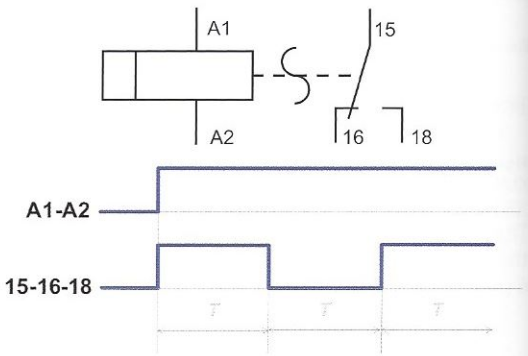


Figure 7.13 – Recycle timer

A recycle timer, Figure 7.13, changes the contact status when power is applied at A1-A2 and continues to switch on and off at regular intervals (*T*). Removing the power resets the function.

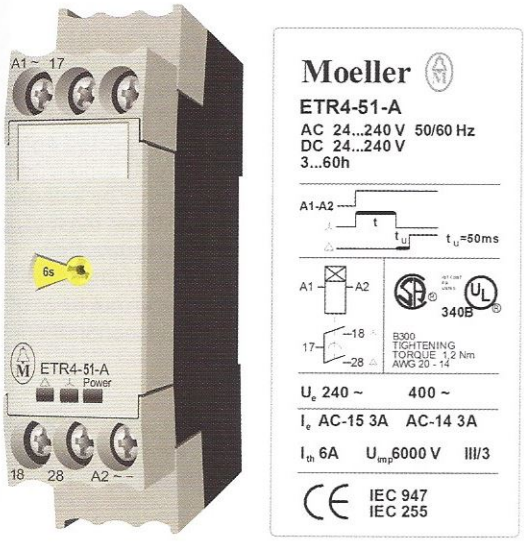
A recycle timer is called a Symmetrical Recycler if intervals are equal. They may also be called Duty Cycling, a recycle timer Repeat Cycle, Delay on Operate and on Release, On/Off Dual Delay, Flasher and Dual-Delay.

Each of these functions can have an extension name of either –On or –Off as well as be initiated with applying or removing of steering signals. A complete set of the 35 functions created in this way are included in Appendix 5.

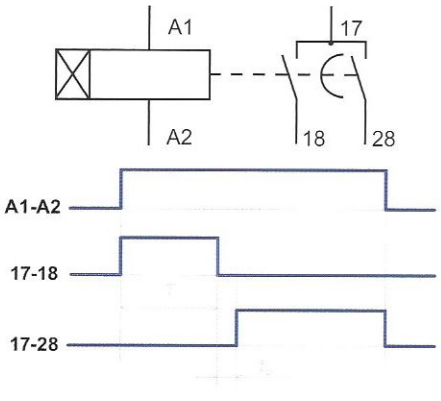
All off-timers operate with either an initiate switch or an initiate loop.

7.2.6 Star–Delta Timer

The star-delta timer, Figure 7.14, is designed as a control measure for starting-up squirrel-cage motors. Star-delta starters are used in three-phase systems (Chapter 9). When starting heavy electric motors, high initial loads are reduced.



a) b)



c)

Figure 7.14 – a) Kl.Moeller ETR4-51-A Star-Delta timer b) Data sticker c) Contact designation and flow chart

The timer employs two separate timing circuits: a variable timing circuit for the changeover from star- to delta- mode (*T*) and a fixed timing circuit (*tu*), Figure 7.14a, with 50 ms for the transition time from de-energising the star-contactor to energising the delta-contactor. The Relay symbol and flow charts are shown on a sticker (Figure 7.14b, c).

When the supply voltage is applied across the A1-A2 terminals, the first internal output-relay, contacts 17-18, energise instantly. Once the time delay has elapsed, contact 17-18 opens, de-energising the first relay and commencing the second fixed time gap of 50 ms (tu). Once 50 ms has elapsed the second output relay, contacts 17-28, close until the supply is removed from A1-A2.

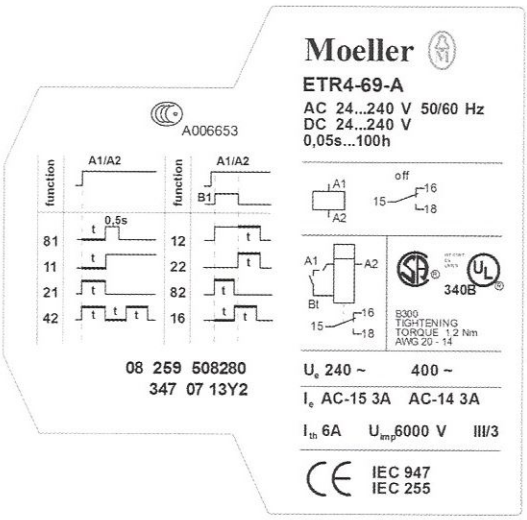
In the equipment shown, timing is displayed as a flashing green LED and once the timing is complete, the green LED will exhibit a steady light. The Intermediate Star contact status is monitored by the (Y) LED and the Delta contact status monitored by the (Δ) LED.

7.3 Multifunction Timer

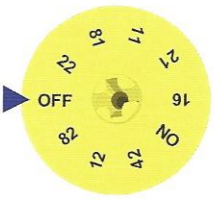
Multifunction timers (MFT) are the alternative to a number of single function timers.

A variety of functions can be selected using a rotary switch, Figure 7.15c, which displays either a function symbol, eg ☒ is referred to as on-timer, ■ is off-timer, ⎍ is interval-timer or a function-setting digit code. The range and time of rotary switch adjustment procedures are similar to that explained in 7.2.2.

a)



b)



c)

Figure 7.15 – a) Multifunction timer Kl.Moeller ETR4-69-A b) Side sticker data c) Function dial's overview

Different units use different function identifications. Figures 7.15b and 7.16 illustrate the function charts for the Kl.Moeller ETR timer series, where each function bears a particular code number. This code uses the third rotary switch, located in the front panel's slot, Figure 7.15c, to set the function.

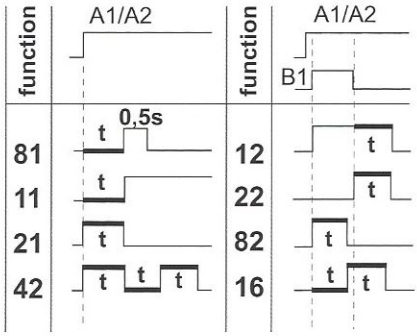


Figure 7.16 – MFT combined function charts

The function charts are divided into two columns (Figure 7.16). The functions combined in the left column are initiated by applying the power supply across terminals A1-A2.

Functions combined in the right group depend on the initiate switch 'B1' status and should be referred to in a similar way as Off-timers.

Function charts are available from the manufacturer's data enclosed with the timer. Figure 7.18 shows some examples.

7.3.1 Advanced Timer Features

Several manufacturers provide advanced timer features such as 'one-shot' (one measured output pulse for every transition of the input from de-energised to energised) and 'recycle' (repeated on/off output cycles for as long as the input connection is energised). Others are managed either by a single function time relay or multifunction timer, most of which have two independent internal relays that allow independent operation for each changeover contacts' group.

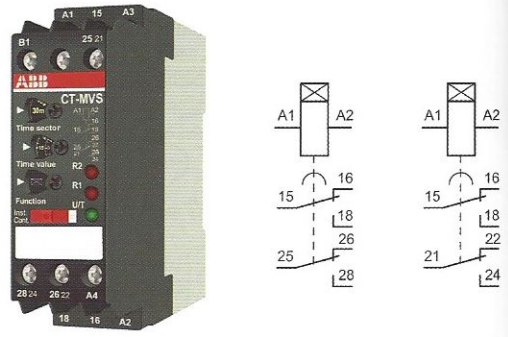


Figure 7.17 – CT MVS

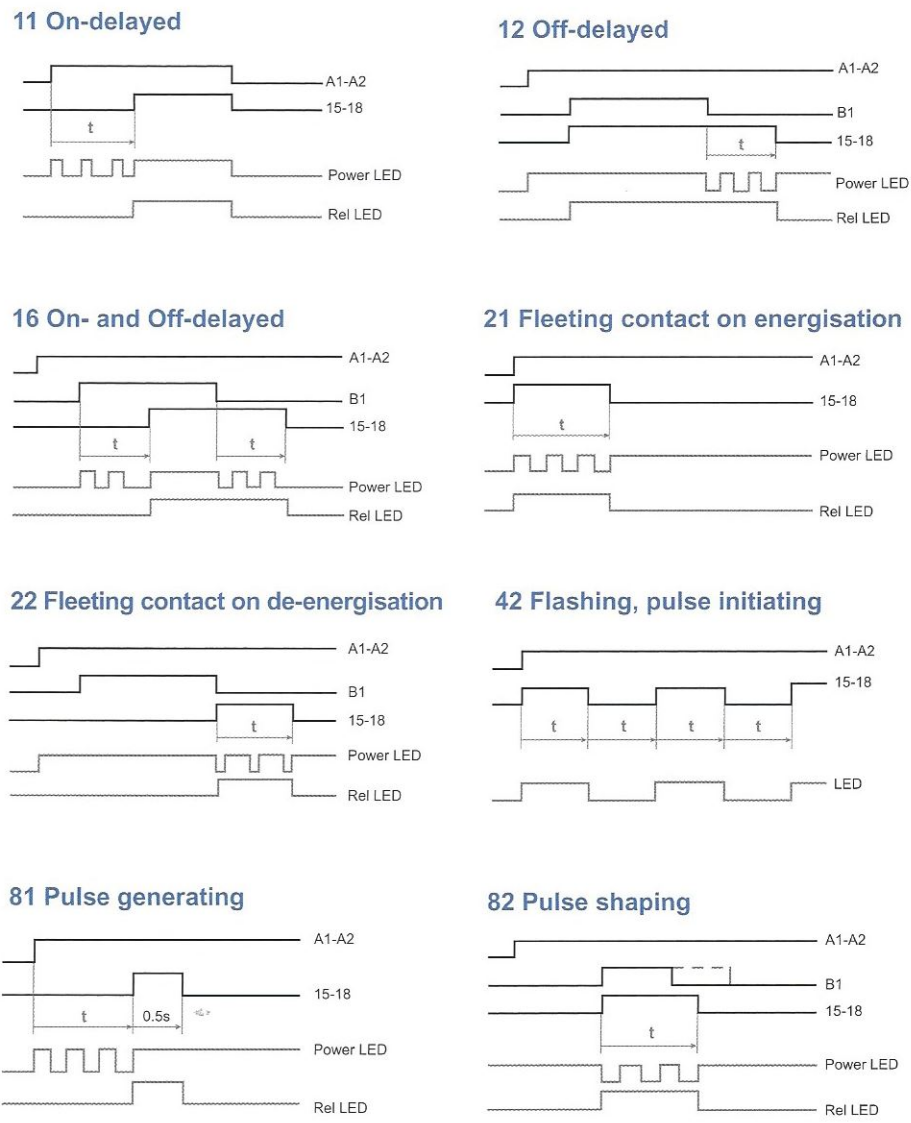


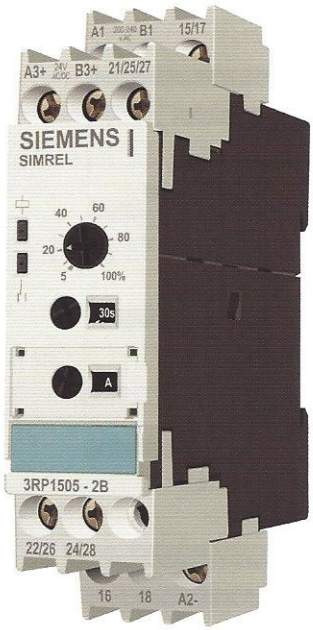
Figure 7.18 – Kl.Moeller Multifunction Timer ETR4-69-A function charts

Figure 7.17 shows a CT-MVS timer by ABB which has a second changeover contacts group, marked with double digits 25-26-28. These are represented in large print, while digits alongside (21-22-24) are in small print. The meaning of this code is:

25-26-28 - time delayed contacts operated together with 15-16-18 as on-delayed;

21-22-24 - instantaneous contacts operated independently on group 1.

Up to 16 functions can be performed by a single multifunctional timer.



a)

Multifunction timing with 16 functions:
A - On delay;
B - Off delay with auxiliary voltage;
C - On and Off delay with auxiliary voltage;
D - Flashing start with brake;
E - Passing make contact function;
F - Passing brake contact function with auxiliary voltage;
G - Pulse shaping with auxiliary voltage;
H*- Additive on delay with auxiliary voltage;
A*- On delay and instantaneous switching;
B*- Off delay with auxiliary voltage and instantaneous switching;
C*- On and Off delay with auxiliary voltage and instantaneous switching;
D*- Flashing start with brake and instantaneous switching;
E*- Passing make contact function and instantaneous switching;
F*- Passing brake contact function with auxiliary voltage and instantaneous switching;
G*- Pulse shaping with auxiliary voltage and instantaneous switching;
YΔ - Star-Delta function.

b)

Figure 7.19 – a) Illustrates Siemens Simrel 3RP1505 timer, b) A set of 16 functions available

7.3.2 Programmable Multifunction Timers

In the late 1990s, electronic appliance manufacturers began to use logic controlled technology for multifunction timers.

The Crouzet TOP 948 programmable multifunctional timer, shown in Figure 7.20, provides a choice of eight initial switch dependant functions which can be preset via the touch screen buttons on the operator interface:

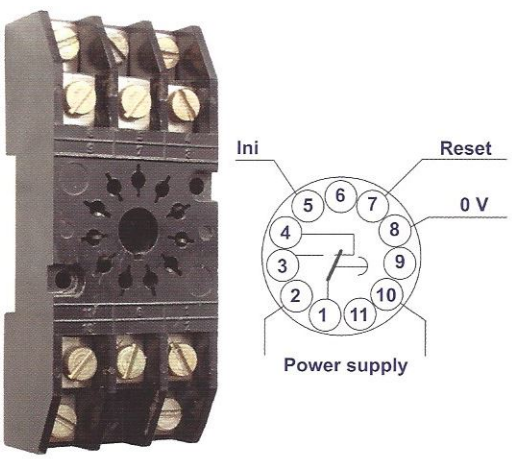
A – delay on make
Ab – delayed single shot
B – single shot
C – delay on break
D – repeat cycle
Di – repeat cycle on time first
H – interval
T – on delay with memory.

Figure 7.20 – Crouzet TOP 948 MFT

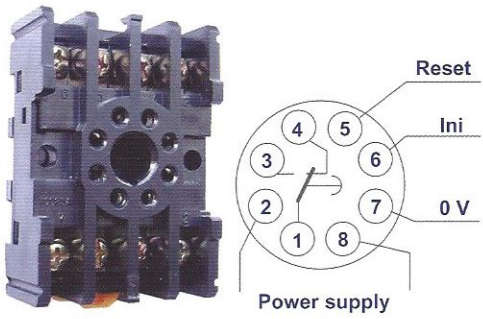
The timer has a plug-in design and uses the 11-pin or 8-pin 35 mm DIN rail base, the connective features are illustrated in Figure 7.21a and b.

The LCD and front panel touch screen buttons allow programming and status to be monitored, operational function, time remaining, time preset value, relay contact status, etc. Time and function adjustments are stored in the EPROM (Erasable Programmable Read Only Memory) and supported with an inbuilt Lithium battery.

Each function is defined from function charts, as shown in Figure 7.22.



a)



b)

Figure 7.21 – a) 11-pin DIN rail base and connection features b) 8- pin DIN rail base and connection features

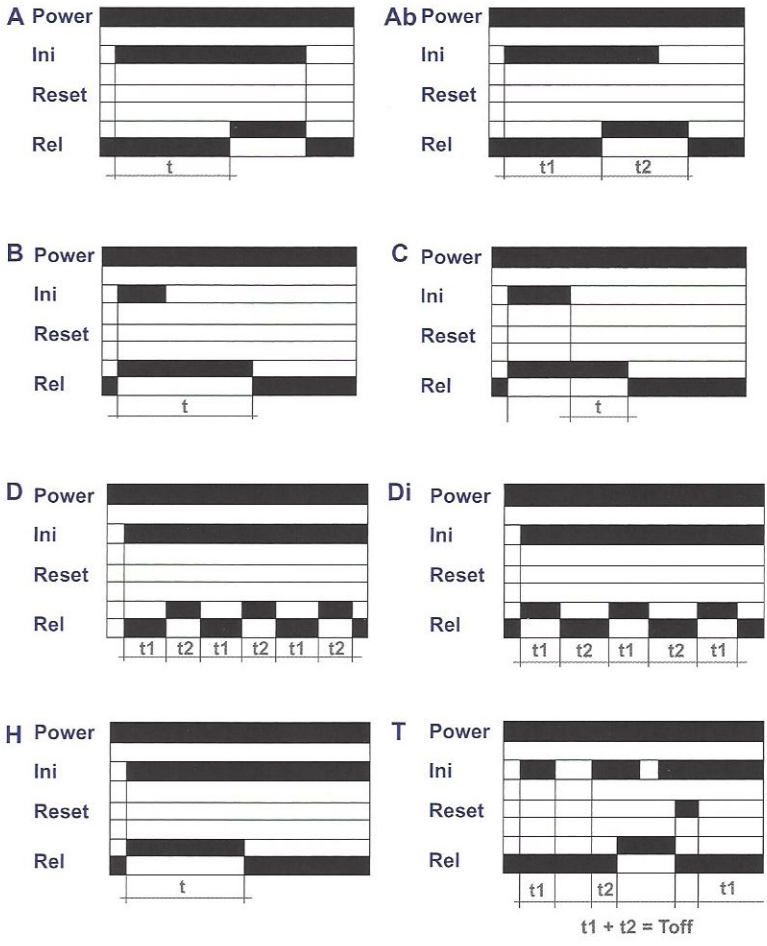


Figure 7.22 – Crouzet TOP 948 function charts

8 Protection and Monitoring Relays

8.1 Introduction

Protection and monitoring relays ensure safety and a high level of system availability by monitoring electrical power (voltage, current and frequency).

An important function of monitoring relays is early error detection. This makes it possible to respond to irregularities before it is necessary to switch off part or all of a system. Monitoring relays are not intended to substitute fuses or motor protection switches. Instead, they signal irregularities at an earlier stage before the corresponding protective devices are tripped.

Trips from a thermal origin are linked to current imbalance, an abnormal temperature-rise of the PTC (Positive Temperature Coefficient) thermistor probes, cosφ measurement dropping too low, locked rotor and over-torque detection, underload, earth fault currents, phase rotation reversals and prolonged starting.

Only a few of the trips listed in the control circuits are used onboard ships and are restricted to essential electrical equipment:

- Current monitoring relays
- voltage monitoring relays
- phase imbalance and phase sequence relays
- PTC relays.

Some other terms commonly used for this subject are outlined below.

Starting override – Measured values outside the tolerated range are ignored during startup. This is when the starting override is active. The purpose is to tolerate brief fluctuations, such as motor inrush currents.

Response delay – Threshold value violations are accepted within the delay time. A signal is only generated if the threshold value violation continues beyond the delay time.

Threshold value – If the measured value passes the set minimum or maximum, the relay will trip.

Reset value – The value where the relay picks up again.

Hysteresis – The range between the threshold value and the reset value.

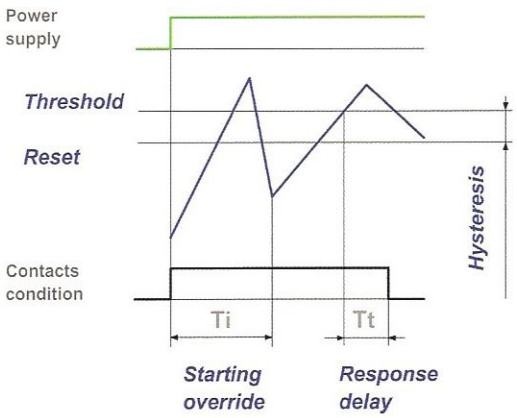


Figure 8.1 – Current monitoring relay function diagram

8.2 Current Monitoring Relay (over/under current monitoring relay)

Overcurrent relays are used to protect sensitive equipment against over or under current conditions. By using Current Transformers (CTs), these protective relays monitor large AC currents common to large motor starters, circuit-breakers and transformers. Figure 8.2 shows a CT which steps down the monitored current to a secondary (output) range of 0 to 5 amps (AC) to power the protective relay. If the monitored current becomes excessive, the relay triggers a contact switching auxiliary control circuitry to the breaker's trip coil. By using the selected time delay between 0.05 and 30s, short current peaks can be bridged.

Figure 8.2 – Current Transformer

Connecting the CT to the current monitoring relay terminals is depicted on the relay diagram's symbol (Figure 8.3). Terminals coded with the letter *B* represent connections to the current transformer. Terminals B1 to B3 connect CTs with different step down current ratios. *C* shows another connection terminal, common for any CT ratio.

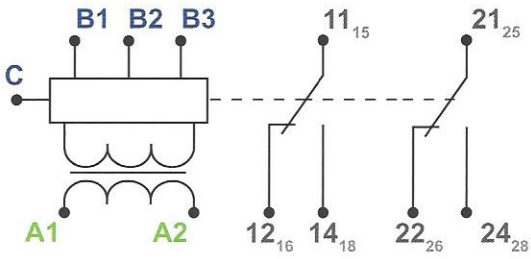


Figure 8.3 – Current monitoring relay

Figures 8.4 and 8.5 are an example of a current monitoring relay and a related electrical diagram. The power is applied across A1/A2, the current signal being monitored is applied across B1 and C. Depending on the measurement of the current ratio, the following connections are allowed: B1/C: 3-30 mA, B2/C: 10-100 mA, B3/C: 0.1-1A. The relay operates with changeover contacts, the motor starter control circuits use NO (normally open) contacts in series with stop button contacts (Figure 8.5). The result is that an occasional break in the power supply will stop the motor.

Figure 8.4 – Current monitoring relay ABB

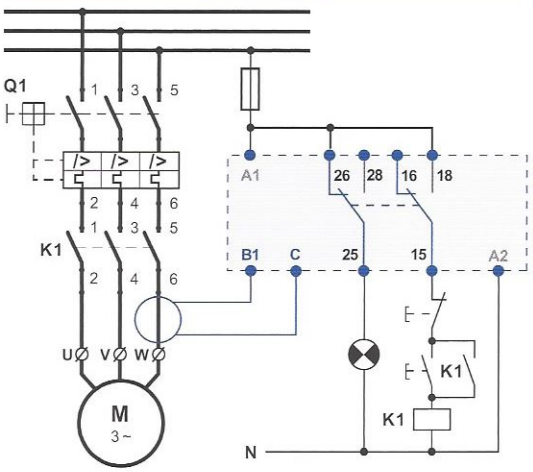


Figure 8.5 – DOL starter with current control

The illustrated current monitoring relay 'CM-SRS' from ABB, Figure 8.4, incorporates two groups of changeover contacts. Each contact terminal is assigned with a reference number, in large print (11-12-14, 21-22-24) and in smaller print (15-16-18, 25-26-28). This notation indicates the relay can operate both contact groups, either with or without a time delay, depending on the rotary selector switch (Tv) position.

Whatever mode of operation is adjusted for the relay (either instant or delayed), only one relevant reference number will be used throughout a diagram.

Relay set for overcurrent detection (*I*>)
If the current is greater than the set threshold, the output relay is energised, with or without a time delay. When the current returns to a value below the threshold, depending on the hysteresis setting, the relay is instantly de-energised (Figure 8.6).

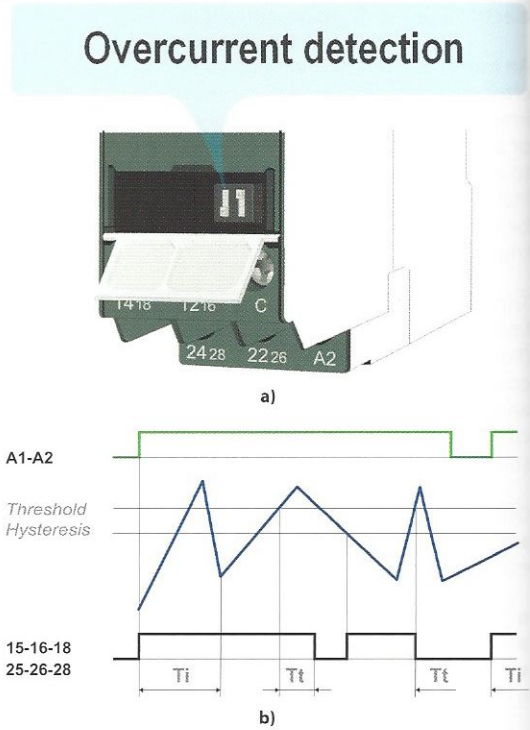
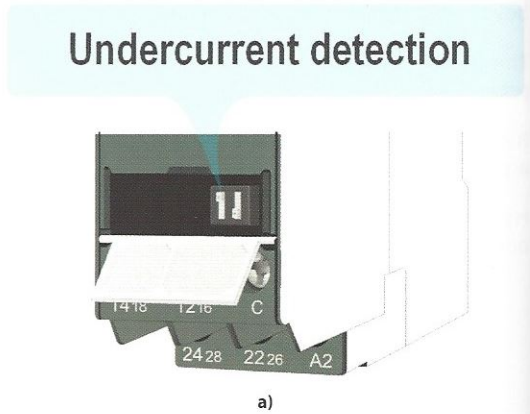


Figure 8.6 – a) Overcurrent detection setting
b) Current monitoring relay function diagram - function I> overcurrent

Relay set for undercurrent detection (*I*<)
If the current is less than the setting threshold *I S1* (Figure 8.7), the output relay is energised, with or without a time delay. When the current returns to a value *I S2* above the threshold, depending on the hysteresis setting, the relay is instantly de-energised (Figure 8.7).



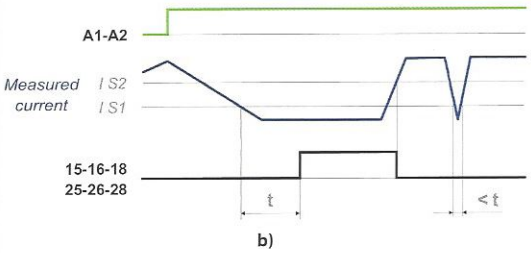


Figure 8.7 – a) Undercurrent detection setting
b) Current monitoring relay function diagram - Function I< undercurrent

8.3 Phase Imbalance Monitoring/ 3-phase Voltage Monitoring Relay

If one phase of a three-phase system fails, eg if a fuse blows, a motor may start, but running motors may be damaged by the unequal loading. If the motor continues to run under nominal load the windings will overheat. As the thermal overload relays and/or the fuses may not protect the motor from damage due to single phasing, protection relays are used to enforce the motor starter trip if supply voltage asymmetry occurs. Asymmetry refers to a drop in the voltage level in at least one phase. The most common cause of asymmetry is an unequal load distribution in the conductors.

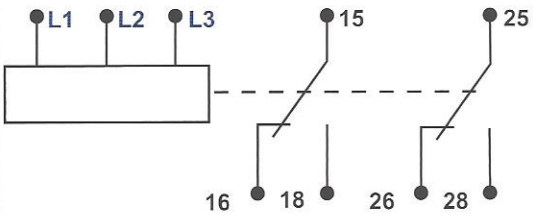


Figure 8.8 – Phase imbalance relay

Relays used to protect motor starters from voltage asymmetry are called phase failure and phase imbalance relays (the symbol is illustrated in Figure 8.8).

Figure 8.9 illustrates the Telemecanique RM4 series phase monitoring relay. A diagram of a motor starter control using phase monitoring relay protection is given in Figure 8.10. By reading the current in all three phases, the relay trips when an imbalanced threshold has been reached.

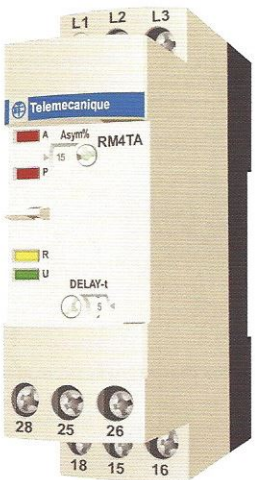


Figure 8.9 – Phase monitoring relay

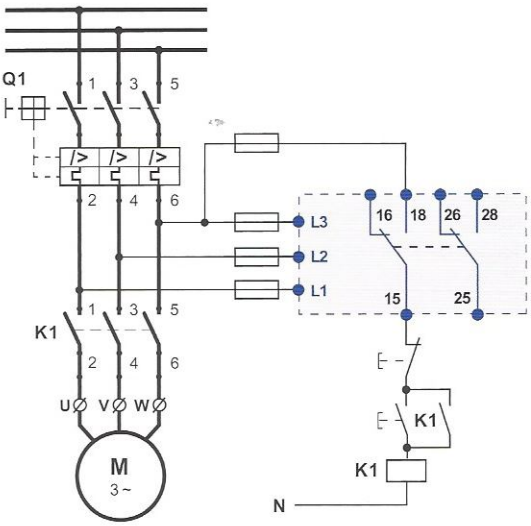


Figure 8.10 – DOL starter with phase imbalance control

Phase imbalance relays incorporate two groups of changeover contacts, which are assigned with reference numbers, 15-16-18 and 25-26-28. These show that the relay operates contact groups with a time delayed adjustable rotary switch. In addition, the time function (On-delay or Off-delay) can be preset with another rotary switch.

An example of a phase failure and phase imbalance relay function chart is illustrated in Figure 8.11.

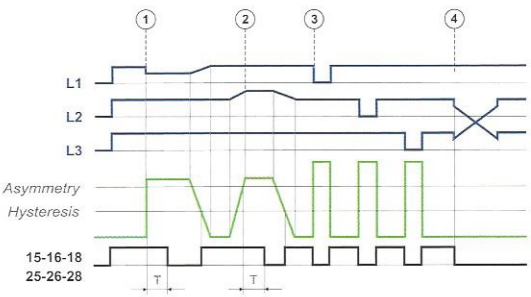


Figure 8.11 – Phase sequence and asymmetry monitoring relay function chart

When three-phase power is applied across terminals L1-L2-L3 and there is no asymmetry between the phases, the relay will become active, changing the contacts over (15-16 open, 15-18 close, 25-26 open and 25-28 close). The relay is now connected with an NO contact 15-18 in series with the starter control and allows the motor to run, see Figure 8.10. This continues until one phase voltage drops (1). From there if the phase voltage does not recover within the preset time gap (T) the relay trips (contacts 15-16 close, 15-18 open, 25-26 close and 25-28 open), stopping the motor (Figure 8.10). The relay will also trip when the preset time has elapsed in the event of overvoltage (2). If the voltage in one phase is completely lost, the relay contacts trip instantly (3). In the event of a phase polarity problem, the relay does not allow the motor to start (4).

A function chart representing over- and under-voltage protection is illustrated in Figure 8.12.

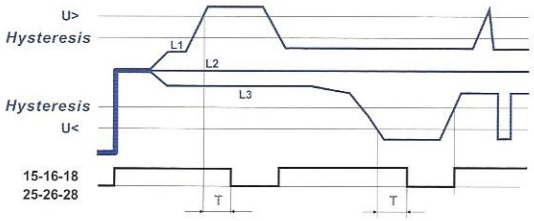


Figure 8.12 – Over and undervoltage monitoring relay function chart

8.4 Thermistor Protection Units (PTC Relays) for Use with PTC Probes

8.4.1 Introduction

Thermistor protection units continuously monitor the temperature of the machines which are to be protected (motors, generators, etc) by using PTC thermistor probes which are embedded in the machine windings.

Figure 8.13 – Single PTC probe with shrunk-sleeve

If the nominal operating temperature of the probes is reached, PTC relays convert the rapid increase in resistance into a switching function that can be used to switch off the machine or signal a fault.

Thermistors are resistors whose resistance varies with temperature. A Positive Temperature Coefficient (PTC) thermistor's resistance increases with a rise in temperature.

8.4.2 Thermistor Probes

There are two basic types of thermistors, NTC (Negative Temperature Coefficient) and PTC (Positive Temperature Coefficient).

The NTC thermistor is more accurate and best suited for precision temperature measurement.

PTC thermistors have a non-linear resistance/temperature response and, at a specified temperature, the resistance changes rapidly to a high value. PTC thermistors are particularly suited as temperature probes for monitoring the windings of electric motors and for use in simple fail-safe circuitry. Figure 8.14 illustrates the motor's junction box, where PTC probe terminals are connected on top of the main terminals (black cable/blue conductors).

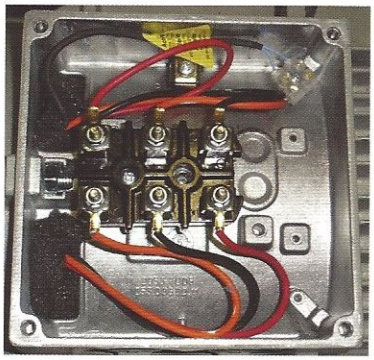


Figure 8.14 – Motor terminal box

If the electric motor is equipped with PTC probes, the relevant PTC symbol, Figure 8.15a, appears adjacent to the motor's symbol on the starter's diagram, as illustrated in Figure 8.15b.

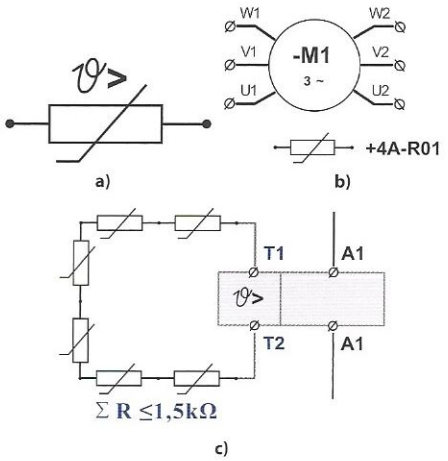


Figure 8.15 – PTC probe diagram definition

Once a motor temperature (response temperature ϑ), monitored by a PTC probe, is exceeded, the controlled circuit can be switched off through a PTC relay connected with the probe.

The type of motor, location and insulation class will determine the type of PTC thermistor probes which are incorporated.

PTC probes are classified according to their response temperature. The relationship of resistance to temperature for a single PTC probe is illustrated in Table 8.1 and Figure 8.16.

Temperature °C	Resistance Ohm	Voltage V
-20 to ϑ –20	250 max	2.5
ϑ –5	550 max	2.5
	1000 max	2.5
ϑ +5	1300 max	2.5
ϑ +15	4000 max	7.5

Table 8.1 – Single PTC probe data table

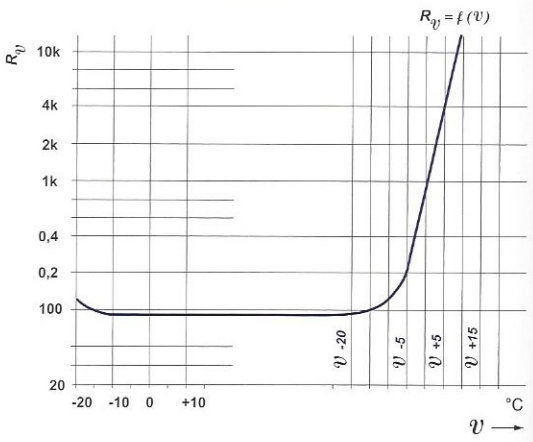


Figure 8.16 – PTC probe characteristic curve of resistance against temperature

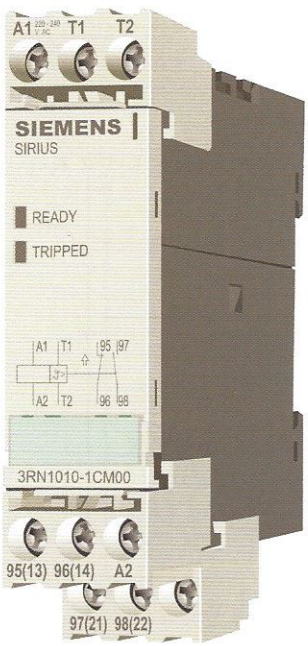
8.4.3 PTC Relays

Thermistor Protection Units that use embedded PTC thermistor probes have terminals assigned with code *T1* and *T2*. These terminals are to connect PTC probes.

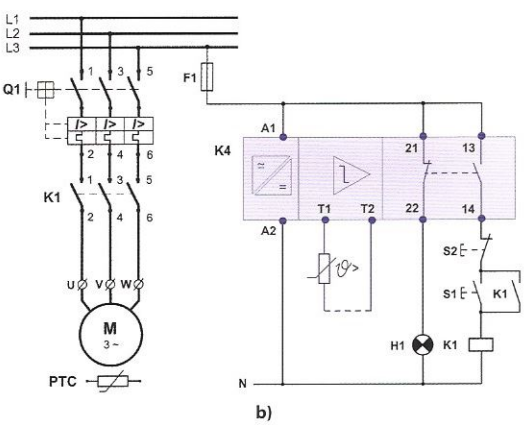
Irrespective of the manufacturer, all PTC relays operate in a similar manner, ie:

- When a power supply is applied across terminals A1, A2 (power supply), the relay triggers the contacts
- if a power supply is lost, contacts A1 and A2 will return to their normal condition
- if there is a short circuit through the PTC probe terminals T1 and T2, the relay turns off and the contacts return to their normal condition
- as PTC units use the closed circuit principle they also respond to a break in the sensor circuit T1-T2
- the resetting of a PTC relay is either automatic when the cooling down time for the PTC probe elapses or by using a reset button in front (if fitted).

8.4.4 PTC Relay Circuit Diagrams



a)



b)

Figure 8.17 – a) Siemens Sirius 3RN1010 PTC relay b) PTC relay's diagram sample

The diagram, shown in Figure 8.18, refers to the connection diagram in Figure 8.17b, and explains the working principle of a PTC relay.

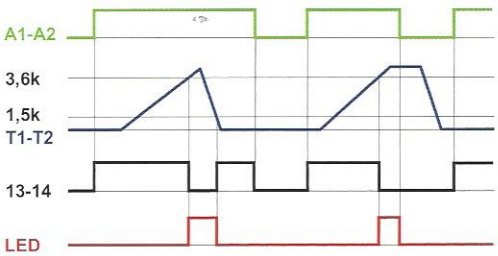


Figure 8.18 – PTC relay travel diagram sample

Once power is applied across the relay terminals A1 and A2, the PTC relay will changeover (13-14 close, 21-22 open) under the following circumstances:

- PTC probe circuit is not open
- PTC probe circuit has no short circuit
- PTC probe resistance is within working range.

The cold resistance of PTC probes is around 1,500 Ω at 25°C. When starting the electric motor the temperature will increase, the PTC probe resistance will also increase. If any overload occurs on the shaft of the electric motor, the temperature will continue increasing until the upper limit of around 3,600 Ω when the relay will trip and the contacts return to their normal status (13-14 open, 21-22 close).

8.4.5 PTC Voltage Warning

Motors equipped with PTC probes are supplied with labels/tags warning against high voltages being applied (as seen in Figure 8.14). Figure 8.19 shows a label warning against applying voltages higher than 2.5 V across the PTC relay/probe terminals T1-T2.

Figure 8.19 – PTC probe warning label

It is important that PTC circuits remain disconnected while testing or working on motors equipped with PTC sensors.

8.5 3-Pole Multifunction Protection Relay

Figure 8.20 – Schneider LTM R multifunction protective relay

Electronic protective relays do not always monitor voltage or current they may have highly specialised functions. However, they provide a contact closure signal that switches power to either a circuit-breaker trip coil, a close coil or an alarm panel.

Most protective relay functions are categorised as an ANSI or ISO standard number code. Table 8.2 shows a few examples from that code list.

12	*Overspeed*
24	*Overexcitation*
25	*Syncrocheck*
27	*Bus/Line undervoltage*
32	*Reverse power (anti-motoring)*
40	*Loss of excitation*
46	*Negative sequence undercurrent (phase current imbalance)*
47	*Negative sequence undervoltage (phase voltage imbalance)*
50	*Instantaneous overcurrent*
55	*Power factor*
59	*Bus overvoltage*
81	*Bus over/underfrequency*

Table 8.2 – Protective relay functions' designation numbers

It is common for manufacturers to incorporate several functions in one protection unit.

Figure 8.21 illustrates the multifunction protection relay LTM R from Schneider Electric that manages the following basic functions:

- Measurement of a three-phase current via integral current transformers from 0.4 to 100 A (up to 810 A by external current transformers)
- measurement of earth current by external earth fault
- measurement of motor temperature by PTC probe
- separate inputs and outputs for various motor control modes, fault management and associated functions.

Figure 8.21 shows a LTM R multifunction protective relay being used as a Star-Delta motor starter.

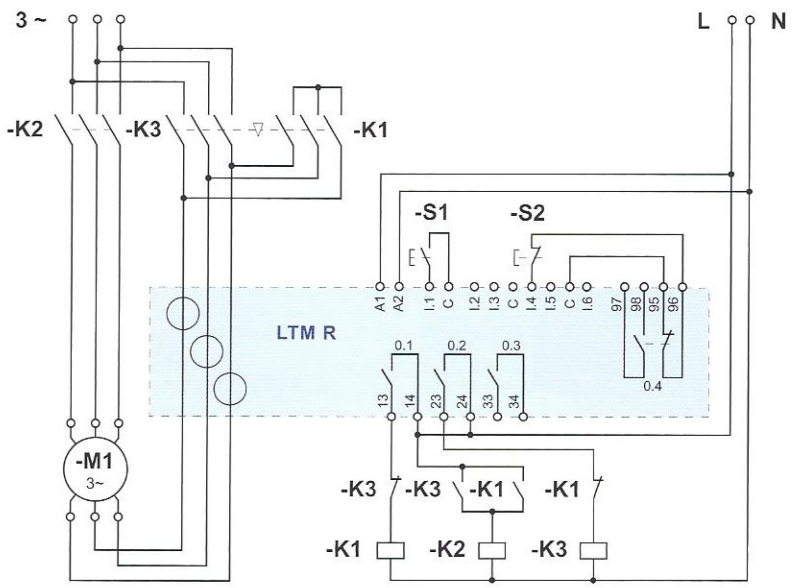


Figure 8.21 – Multifunction relay Schneider Electric LTM R used for Star-Delta starter protection

9 Three-Phase Induction Motors

9 Three-Phase Induction Motors

9.1 Induction Motors

An induction motor works by inducing a current in the rotor by a voltage being applied across the stator winding. This induces a current in the rotor by transformer action and exerts a torque on the rotor.

9.2 Induction Motor Terminal Features

The induction motor stator winding consists of coils that are wound on all the poles of the machine. These are connected together forming a suitable series or parallel circuit on each phase winding.

The terminal block has six main terminals for connecting the incoming power supply cables which are marked in accordance with IEC 60034-8.

Stator winding connections are assigned with the notation U1-V1-W1 and U2-V2-W2. An e-motor terminal is shown in Figure 9.1.

The leads connecting the windings to the motor terminals often have a colour coding system, each phase winding is represented by a different colour, eg black-red-white, as illustrated in Figure 9.2.

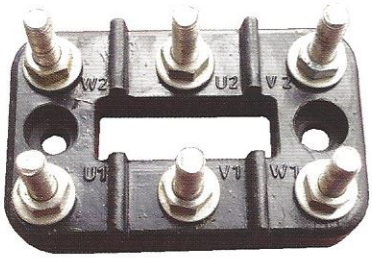


Figure 9.1– Motor terminal block

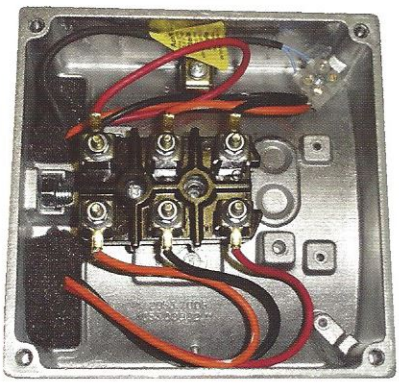


Figure 9.2 – Leads' colour coding system

A single speed three-phase induction motor winding can be connected in either star or delta from the side of the terminal. As seen in Figure 9.3, the configuration can be determined by the position of the terminal link:

- In a star configured motor, links are fitted as in Figure 9.3a and power cable (L1, L2, L3) is connected to U1, V1 and W1;
- in a delta configured motor, links are fitted as in Figure 9.3b and power cable (L1, L2, L3) is connected to U1, V1 and W1 again.

To change the direction of a three-phase motor (star or delta), swap any two of the incoming power cables L1-L2-L3, and reconnect.

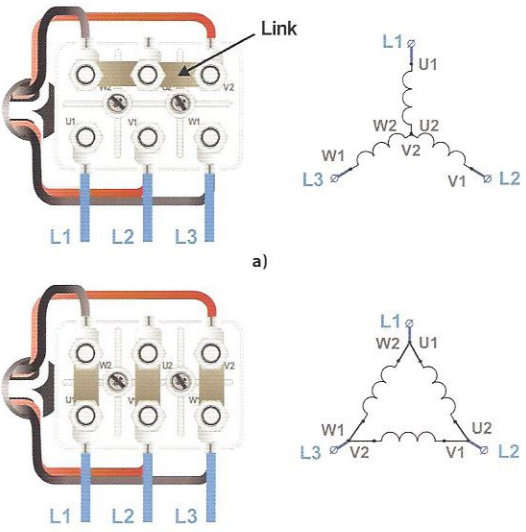
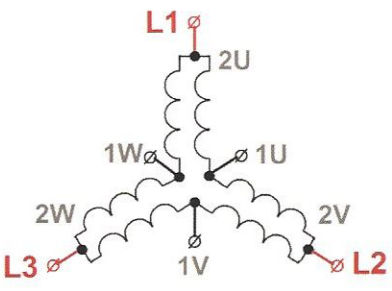


Figure 9.3 – a) Induction motor star configuration
b) Delta configuration

In two-speed motors the terminal identification is different. Figure 9.4 illustrates a three-phase, two-speed motor. The terminals 1U, 1V, 1W relate to the slow-speed winding set and terminals 2U, 2V, 2W relate to the higher speed winding set.



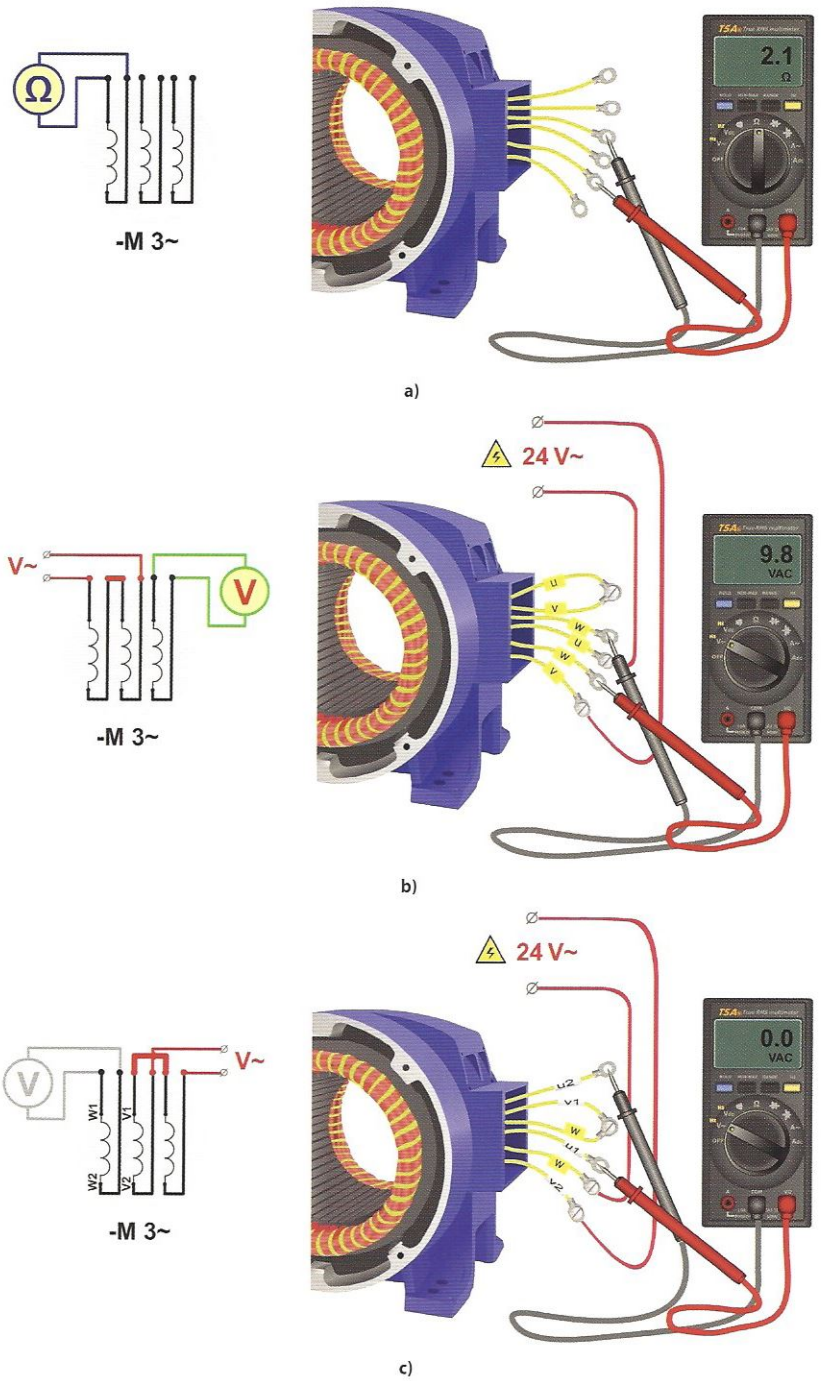


Figure 9.9 – Verifying e-motor winding, beginnings and ends

10 Motors Starters

10.1 Introduction

Starting a demagnetised induction motor requires there to be sufficient energy to magnetise the motor which provides acceleration and kinetic energy. Applying full voltage immediately may create excessive stress and wear on the components, ie the windings, core, transmissions, gears, drives and rotor. High acceleration may cause wear, shaft torque oscillations and failure.

The energy flow to an induction motor (-M) can be controlled by interrupting the power supply using a three-phase contactor operated by a solenoid coil (Figure 10.1a).

This is known as either Direct-On-Line (DOL), across-the-line or direct start. A reversing DOL starter can be seen in Figure 10.1b, which is often used on smaller motor sizes (up to 30kW) or where the supply is strong enough to withstand the starting current surge without causing any unacceptable voltage drop.

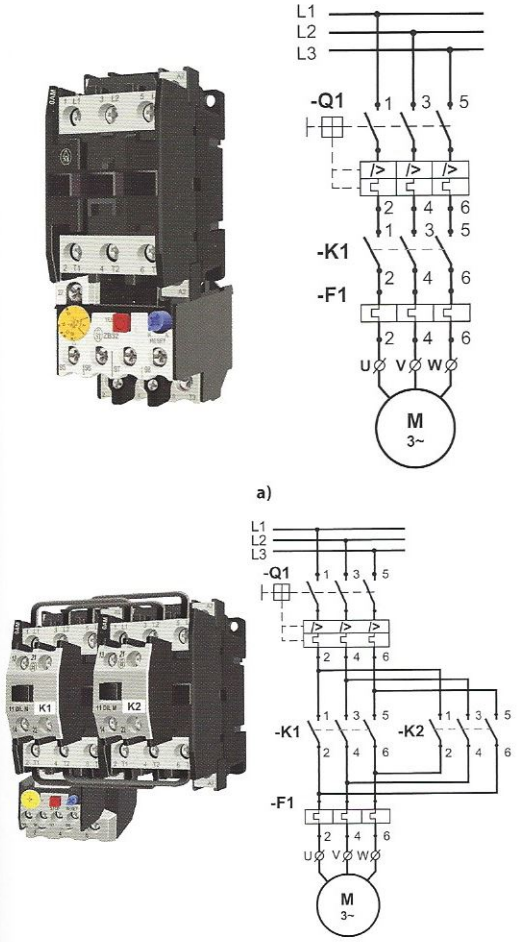


Figure 10.1 – a) DOL starter b) Reversing DOL starter

The most familiar type of reduced voltage starter used on ships is a Star-Delta starter, shown in Figure 10.2. This method of starting is applicable to motors where all six stator terminals are accessible and where the delta connection voltage corresponds to the mains voltage. Star-delta starting is used for motors that start on no-load or have a low load torque and a gradual build-up:

- The starting torque in a star connection is reduced to one third of the direct starting torque, ie about 50% of the rated torque
- the starting current in a star connection is approximately 1.8 to 2.6 times the rated current.

The transition from a star to delta connection must take place when the machine has run up-to-speed. Too quick a build in torque will cause a stabilised run-up speed which is too low, eliminating any advantages of this method. This is the case with machines whose load torque depends on the machine speed, for example in centrifugal machines.

Switching from a star to delta connection must be completed within a preset time gap of 3-12 seconds, depending on the motor's size. The switching function is performed by either a time relay, in some cases this is a pneumatic timing module, or a PLC-based application.

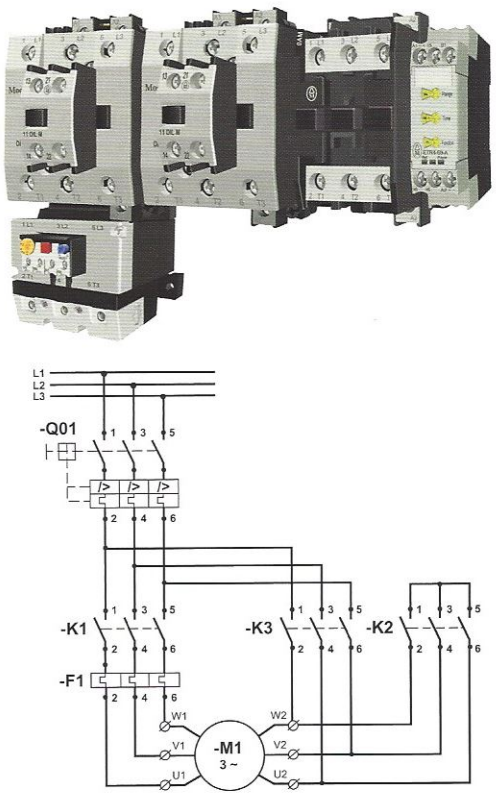


Figure 10.2 – Star-Delta starter

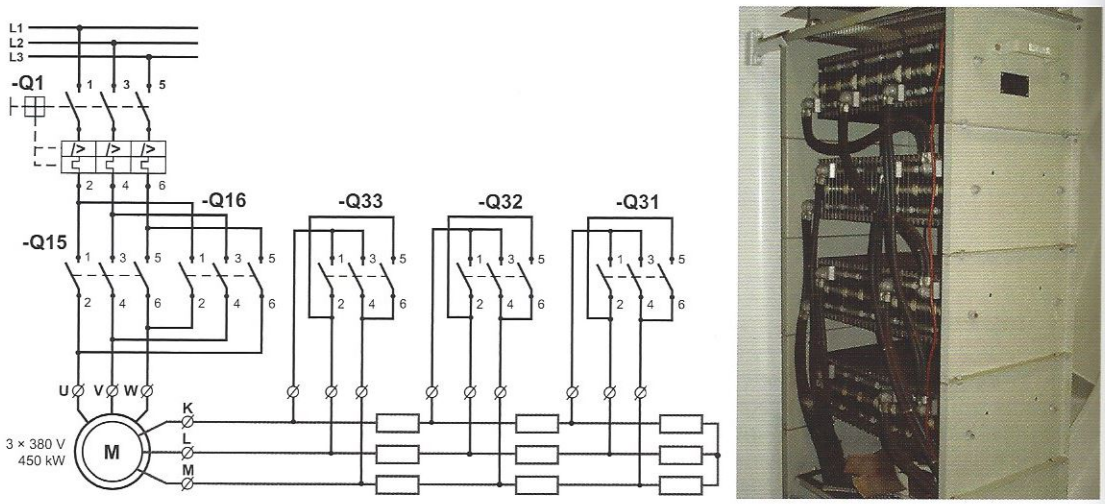
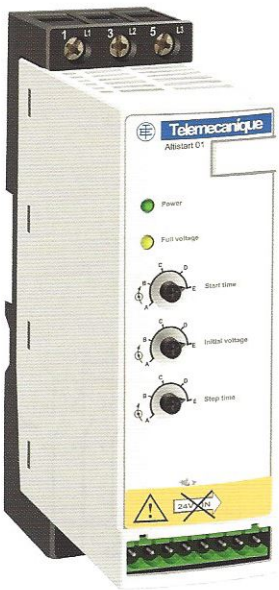


Figure 10.3 – Wound rotor motor starter and resistor module overview

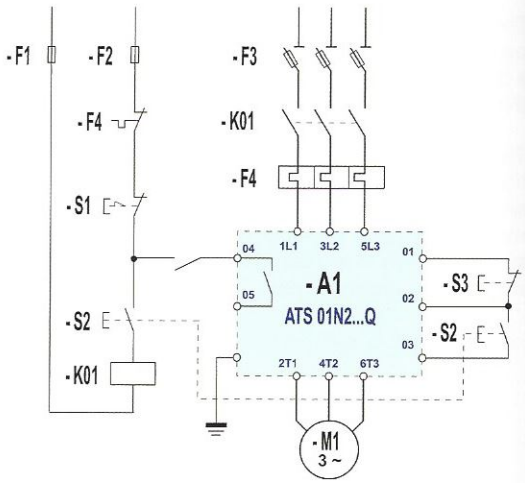
Another system which is used to start large motors uses wound rotor motor starters, eg bow and stern thrusters. This system increases the motor's speed in stages using a set of three-phase resistor modules (0.8Ω per phase) connected across the rotor winding by slip-rings and brushes. Figure 10.3 shows a 450 kW bow thruster starter. The rotor speed is increased in steps, as outlined below:

1. The motor is started and incorporates all the resistors, ie maximum resistance. Q31, Q32 and Q33 are all de-energised maintaining a slow rotor speed.
2. Q31 is energised, reducing the rotor winding resistance and increasing the rotor speed.
3. Q32 energises, reducing the resistance further and increasing the rotor speed.
4. Q33 energises completely bridging the resistor module and achieving full operational speed.

Figure 10.4a shows a Telemecanique Altistart 01 soft starter used for starting 15-75 kW asynchronous motors, providing acceleration and deceleration. The voltage output is controlled by logic. Figure 10.4b is a drawn example for the asynchronous motor control.



a)



b)

Figure 10.4 – a) Telemecanique Altistart 01 soft starter
b) Soft starter DOL diagram

Recently, the dominance of EM starters has been challenged by electronically controlled power semiconductors, mainly SCRs, called soft starters, see Figure 10.4.

Advantages of soft starters include the following:

- Reduced maintenance of associated electromechanical equipment
- lower starting and running currents which reduce cable losses
- contactor switching operations are carried out under ideal conditions
- no current flows during switch on as all switching is carried out by thyristors, which virtually eliminate the need for contact replacement.

In many cases, contactors are no longer employed and are being replaced by controllable circuit-breakers or isolators.

Figure 10.5 shows a soft starter's function chart, the initial output voltage, start time and stop time are adjusted separately from front panel trimmers.

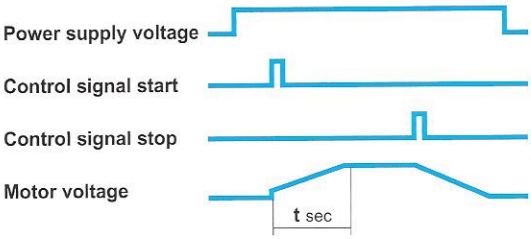


Figure 10.5 – Soft starter's function chart

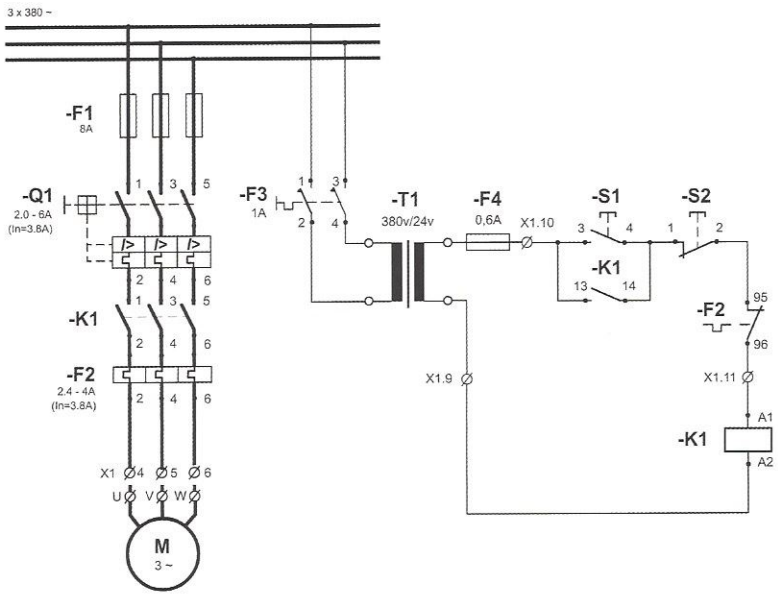
10.2 Direct-on-Line Starting (DOL)

Three-phase magnetic starters apply a full line voltage across the motor windings. The rating of motors that can be started 'direct-on-line' will depend on the capacity of the distribution system and the acceptable busbar voltage drop during starting. It is unusual for any ship to start a motor over 50 kW with a DOL starter, as they produce a high starting torque and a corresponding high current.

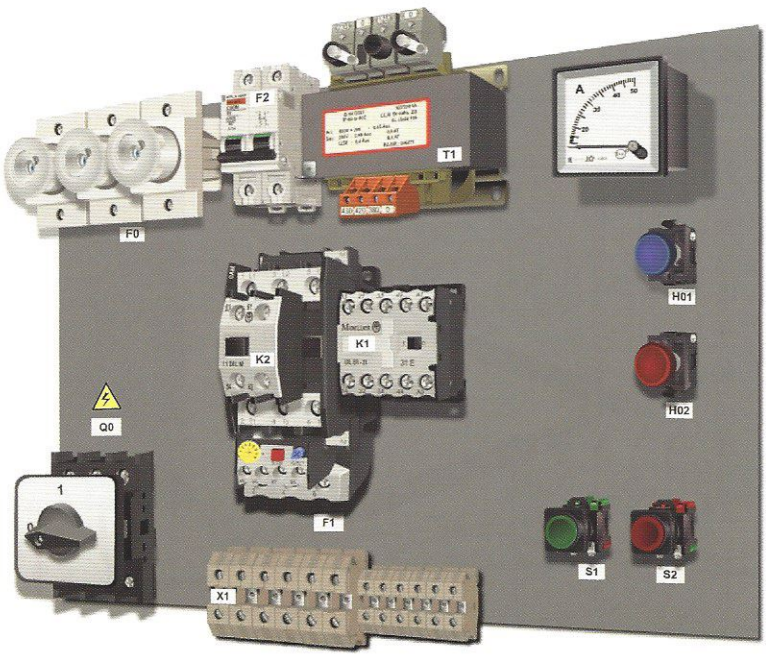
The DOL starter, as shown in Figure 10.6, has two distinct circuits, a power circuit and a control circuit.

The power (or main) circuit consists of the following: fuses (-F1), motor starter protector (-Q1), contactor (-K1), main contacts (1-2; 3-4; 5-6), overload relay (-F2) connecting incoming power lines L1, L2, L3 with the three phase motor. The three pole contactor is a primary component in a motor control circuit. K1 main contacts 1-2; 3-4; 5-6 are designed to carry the starting current.

The control circuit consists of the automatic fuse -F3, transformer -T1, start/stop buttons -S1 and -S2, hold-in contacts -K1 13-14, overload relay F2 with



a)



b)

Figure 10.6 – a) DOL starter control diagram b) DOL starter simulator

auxiliary contacts 95-96 and contactor -K1 magnetic coil.

If additional pilot switches are required for automation, they are connected in series anywhere throughout the terminals. An additional safety pressure switch could be connected between the stop button -S2 terminal 2 and the overload relay -F2 terminal 95 to prevent overload and to stop a pump when the pressure exceeds a preset higher limit.

10.2.1 Operation Basics

In Figure 10.6, power is applied by switching on -Q1 and -F3, introducing a control voltage, potential difference, across the start button terminals S1/3-4 and across the hold-in contacts K1/13-14. As soon as the start button is pressed, current will flow through the NC contact of the stop button -S2/1-2 and also the NC contact of overload relay -F2/95-96 to the coil of -K1. The coil energises, closing the main contacts (1-2; 3-4; 5-6), the three-phase voltage is then applied across the motor winding terminals U1-V1-W1 starting the motor –M. On energising, the contactor will close the auxiliary contacts -K1/13-14, which will remain closed when the start button is released, and the motor will continue to operate. Once the stop button is pressed, voltage to the contactor coil will be lost and the motor will stop. The entire circuit resets itself, waiting for an operator to push the start button again. If the overload relay trips while the motor is running, it will also shut down the motor by opening the NC contacts –F2/95-96.

10.2.2 Troubleshooting DOL Starter Circuits

The ladder diagram is the traditional way to display electrical sequence operations. These diagrams represent the interconnection of field devices, so the activation of one device will turn on another device according to a predetermined sequence of events. The ladder diagram is a useful tool in determining the operation of the devices and for locating problems. The ladder diagram shown in Figure 10.7 is an example of the control diagram illustrated in Figure 10.6a.

Troubleshooting control circuitry begins with testing the line voltage supplied to the control cabinet. To confirm that all three phases are applied to the main contacts of the contactor K1 (1-3-5), the simplest way is to measure the voltage integrity directly across them (Figure 10.8). Assuming all three

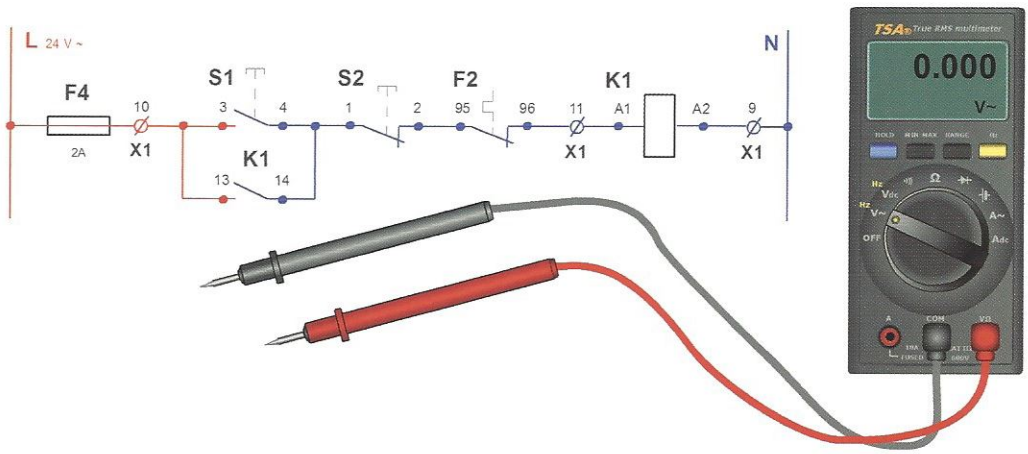


Figure 10.7 – DOL starter ladder diagram

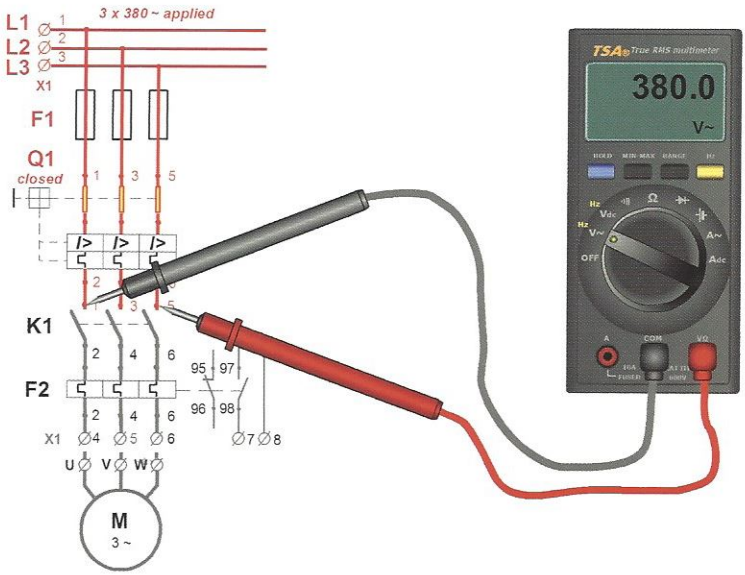


Figure 10.8 – Measuring power supply. The power circuit is shown live (Q1 is closed)

phases are present, ie the circuit is live, voltage can be measured either across the primary winding of transformer T1 or across the load side of the automatic fuse F3. It is possible to get a reading as high as 380 volts, in which case the transformer T1 secondary winding output voltage should be measured. As the control diagram shows, voltage measured across terminals X1/9-10 corresponds to the control circuitry voltage (the secondary voltage of the transformer T1), the reading should be 24 volts AC. If it is, this test proves that fuse F4 has not blown.

If all the control circuitry contacts, stop-button NC contact S2/1-2, overload relay NC contact F2/95-96, are in their normal condition (NC) and the coil of contactor K1 has no wire break (open circuitry), the potential difference should be visible and can be measured across either the start-button terminals S1/3-4 or across the contacts K1/13-14, Figure 10.9. This potential difference is equivalent to the control voltage (24 volts AC) measured across terminals X1/9-10.

This test indicates whether the motor starter control circuits will start the motor. If no potential difference is measured across the start button terminals S1/3-4, the following 'right-to-left' voltage measuring sequence is used for troubleshooting. In this instance terminal X1/10 is used as the common measurement terminal, do not disconnect the DMM red lead from it.

1. Measure the potential differences across X1/10 and X1/11 to determine if the contactor coil has a broken wire or loose terminals.
2. Measure the potential differences across X1/10 and S2/2 in order to check that the overload relay F2 contact 95-96 remains Normally Closed, the relay has not tripped and that there is no break before S2/2.
3. Measure the potential differences across X1/10 and S2/1 to check whether the stop button contact remains Normally Closed or there are no loose terminals.
4. Finally measure the potential difference across X1/10 and S1/4 to ensure that the wiring throughout the motor starter enclosure is uninterrupted.

It should be noted that:

- When troubleshooting DOL control circuits on board a ship, not all the test procedures may be necessary if the failure is traced in the first steps
- actual voltages measured, as illustrated in Figures 10.9 to 10.11 , could be slightly higher or lower than the values stated above.

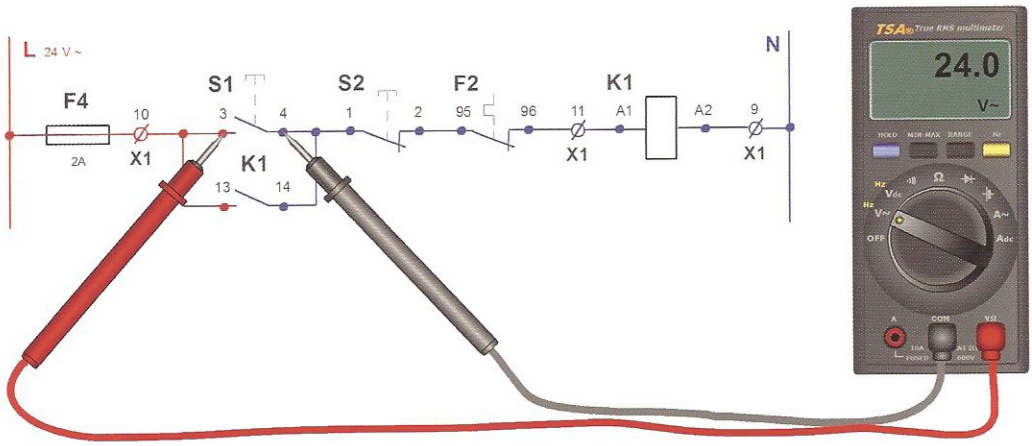


Figure 10.9 – Measuring the potential difference across start-button terminals and 'potential free' contact –K1/13-14)

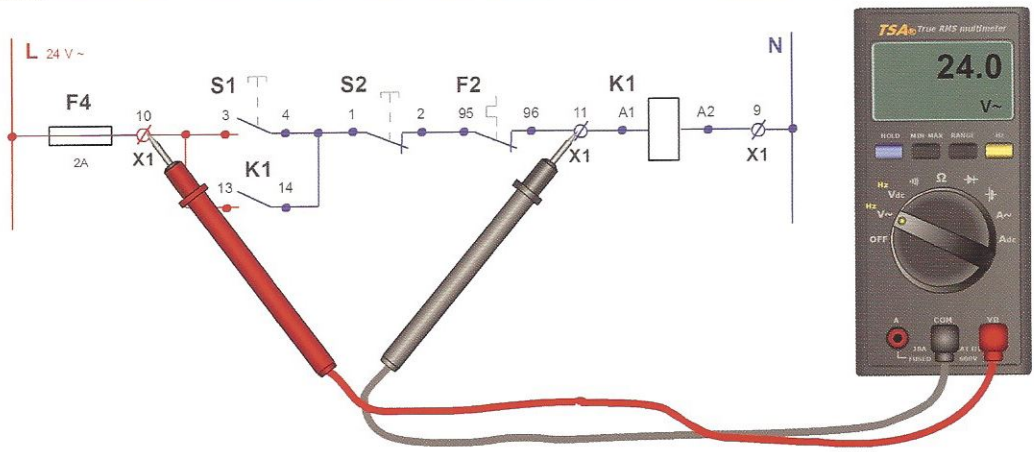


Figure 10.10 – Measuring potential difference across terminals X1/10 and X1/11

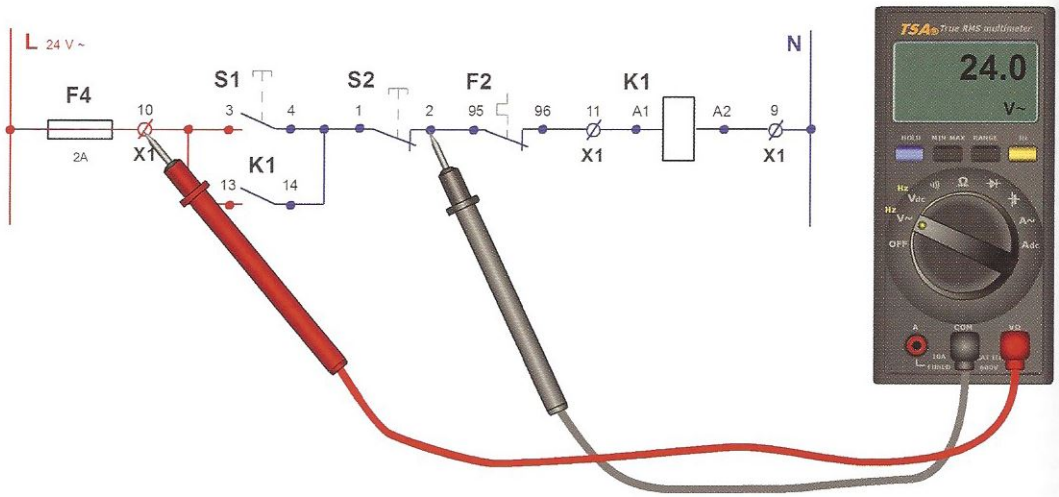
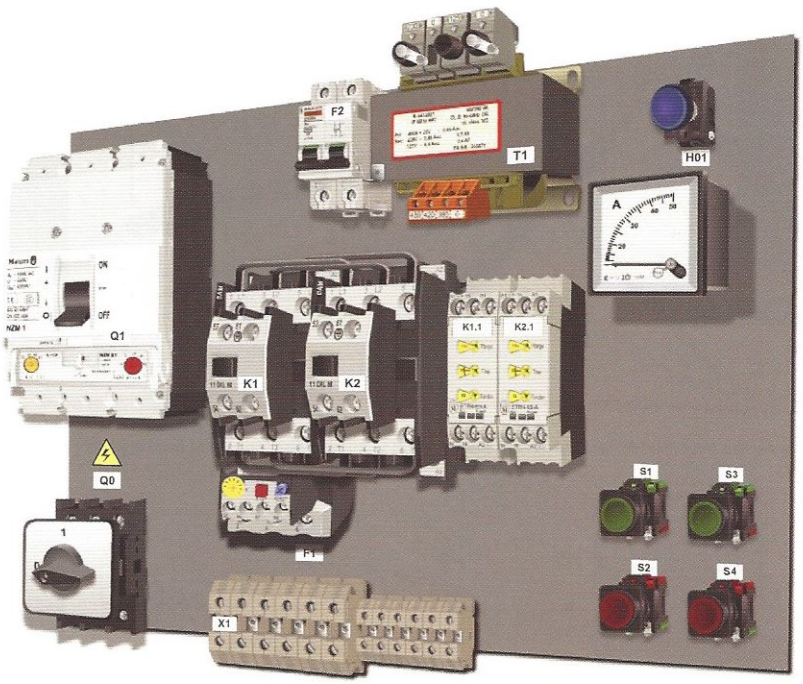


Figure 10.11 – Measuring potential differences across terminals X1/10 and S2/2

10.2.3 Reversing DOL starter

By changing the phase sequence in three phase power circuits of a DOL starter motor, shaft reversing can be achieved. Figures 10.12 a) and b) give examples of power circuits for reversing a DOL starter of an on board supply/extract ventilation starter.

Power for the starter is applied by activating the motor starter protector -Q1. Power for the control circuits is applied by turning the miniature automatic breaker -F2. Depending on which of the contactors (-K1 or –K2) is energised, the starter will run in a direct or reversing direction.



a)

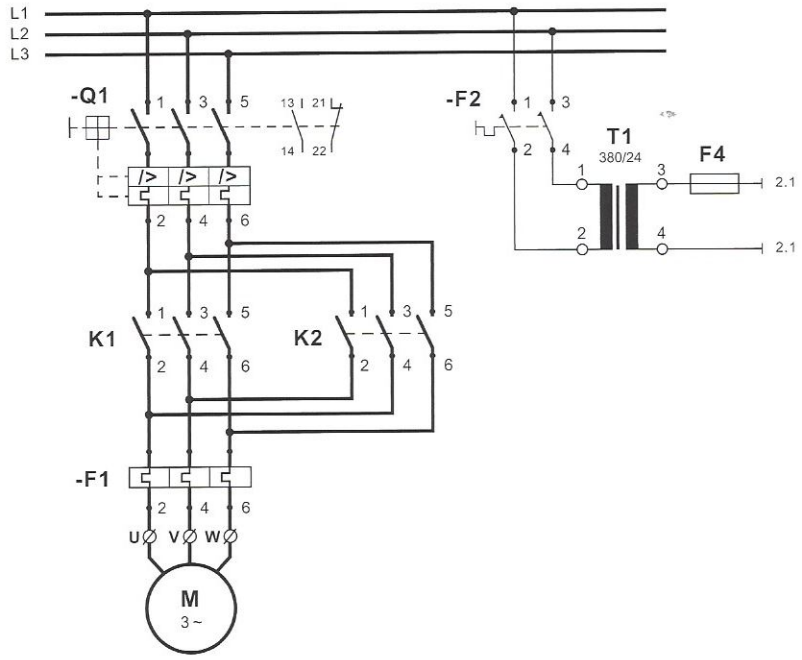


Figure 10.12 – a) Reversive starter interactive simulator and b) reversing DOL starter power circuits

The starter's control circuits, which incorporate the following features, are shown in Figure 10.13:

- Electrical interlocks –K1/21-22 and -K2/21-22 which prevent both reversing contactors being switched on simultaneously
- delayed-off interlocks –K2.1/15-16 and –K1.1/15-16 which prevent the reversing contactor from switching on until the preset time gap of seven seconds has elapsed
- common safety circuits consisting of the –S0 emergency stop button, -F1/95-96 motor overload protection and -Q1/13-14 motor starter protection monitoring contact.

When the start button –S1 is pressed, the current flows through the coil of contactor –K1 holding the auxiliary contact –K1/13-14 closed and starting the motor. Electrical interlocks -K1/21-22 open preventing the reversing contactor –K2 from energising. The delay-off timer –K1.1 opens contact 15-16, preventing activation of the –K2 reversing contactor until the stop button –S2 is pressed and the seven second time delay has elapsed. The delay-off interlocking contact –K1/15-16 must return to the closed position before starting the motor in reverse by the reversing start button -S3 being pressed.

The motor reversing circuit is operated using contactor –K2 and works in a similar way.

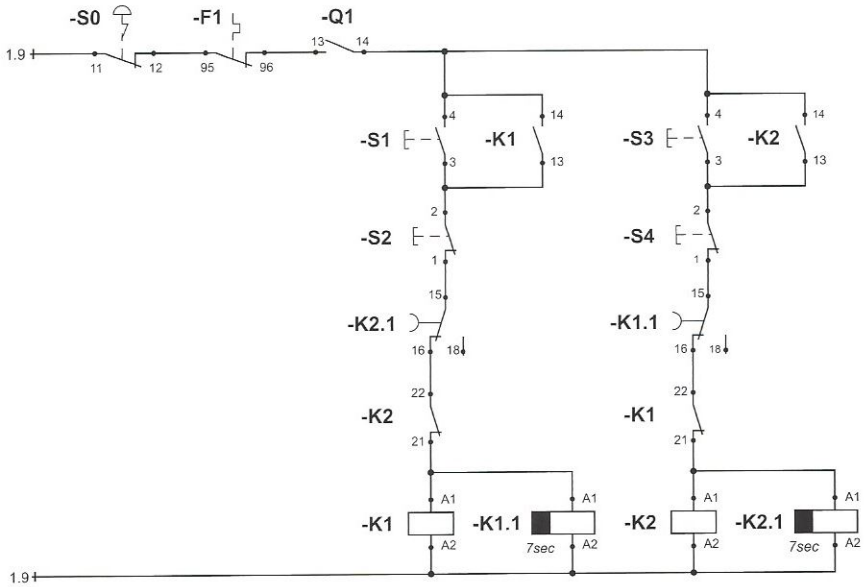


Figure 10.13 – Reversing DOL starter control circuits

10.2.4 Test Your Knowledge

To practice this technique, look at the diagram shown in Figure 10.14 a which represents a MaK Engine Turning Gear control. It is a Reversive DOL Starter with a motor brake that has two interlocks connected through the control circuits. Study the diagram to determine which control points, terminals and contacts you would use for measurements when troubleshooting.

For example, imagine you ran into trouble starting e-motor -M1 by the -S1 pushbutton:

- The circuit is shown in the de-energised state, you should attempt to visualise power being applied and what would change
- the control circuit has a limit switch at the side of the Barring Gear, the NO contact is part of the starter safety system, which is shown in the turning gears' disengaged state
- as the pushbutton -S1 is part of the -K1 contactor circuit and this determines a current path for the -K1 coil, figure out the measurements that you should carry out while troubleshooting
- determine if either of the reversing contactors have any interlocking circuits between them
- determine the function and purpose of timers –K3 and -K4 for both of their terminal groups (21-24 and 15-18).

A more detailed explanation is shown in Figure 10.14 b.

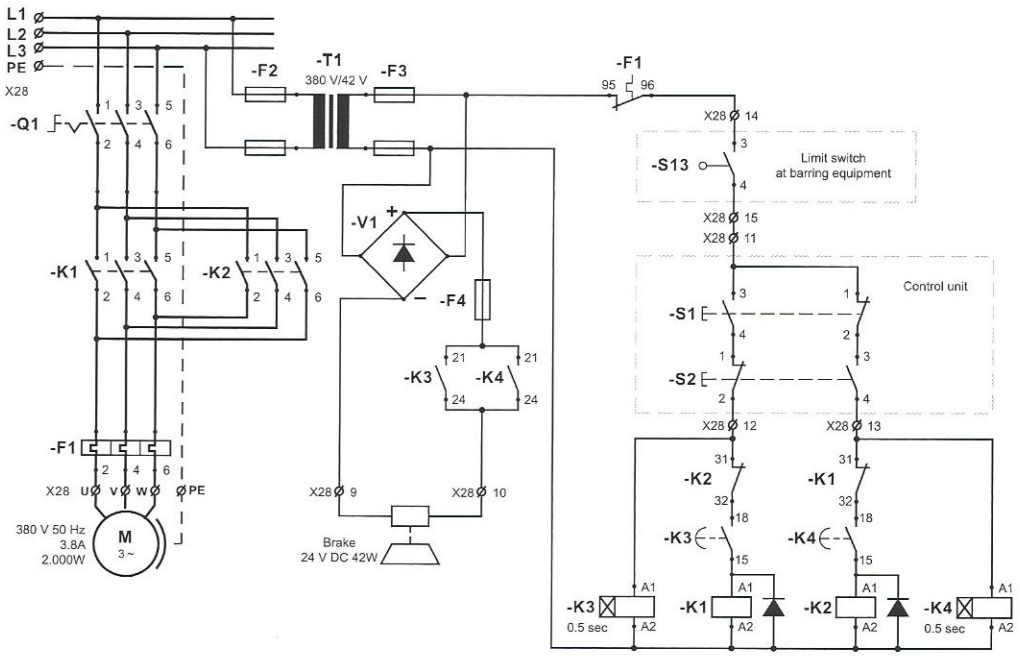


Figure 10.14a – M43 MaK engine turning gear control

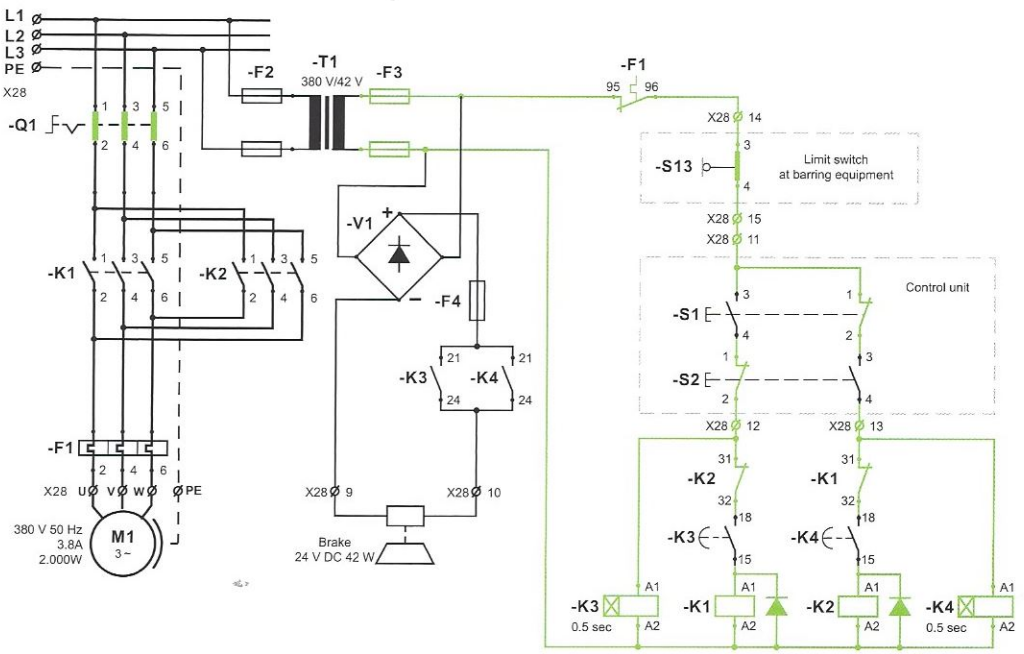


Figure 10.14b – MaK turning gear control diagram (current path)

Additional information to understand control circuitry:
The control diagram in Figure 10.14 b indicates the current's path and follows the sequence below:

On closing –Q1 the secondary winding of the –T1 transformer supplies 42V to the control circuit.

When the turning gear is engaged -S13 will close and its contacts will establish a potential difference across X28/15 – X28/11, or across –S1 start button terminals 3-4 and X28/15 – X28/13 or across –S2 start button terminals 3-4, which can be measured. The circuit will remain on standby until either –S1 or –S2 are pressed.

The troubleshooting task was to check the circuits in relation to the –S1 pushbutton, a detailed description follows.

- Once the –S1 button is pressed the circuit will close, allowing voltage to appear across the delay-on timer –K3's terminals A1-A2
- -K3 closes its instantaneous contact 21-24, introducing voltage across X28/9 and X28/10, supplying DC voltage from the rectifier –V1 to the brake which instantly releases the motor
- after a preset time delay of 0.5 seconds -K3 contacts 15-18 will close introducing voltage across the –K1 terminals A1-A2
- this energises the interlocking circuit of the reversing contactor –K2 opening NC contacts 31-32
- -K1 closes its main contacts 1-2, 3-4 and 5-6, applying voltage across the motor winding terminals U-V-W, starting the motor.

The motor will continue to run while –S1 is pressed.

10.3 Star-Delta Starters

10.3.1 Introduction

The next most common method of starting is to use Star-Delta transition. It is widely used in large motors driving loads over 30kW, such as ballast system pumps, fire pumps, propulsion system pumps and cargo hold fans. This method applies to motors on which all six stator winding terminals (U1-U2, V1-V2, W1-W2) are accessible and connected to the starter, as shown in Figure 10.15. The delta connection voltage corresponds to the mains voltage.

Star-delta should be used for motors which start with either no load or a low load torque and a gradual build-up. The starting torque in a star connection is reduced to one third of the direct starting torque, approximately 50% of the rated torque. The starting current in a star connection is about 1.8 to 2.6 times the rated current. The transition from a star to delta connection must occur when the machine has run up to speed. Too rapid a build-up in load torque reduces the stabilised run-up speed and eliminates any advantage, for example, machines where the load torque depends on the machine speed, eg centrifugal machines.

Switching from the star to delta connection must be completed within a minimum time and is controlled by a time relay or PLC.

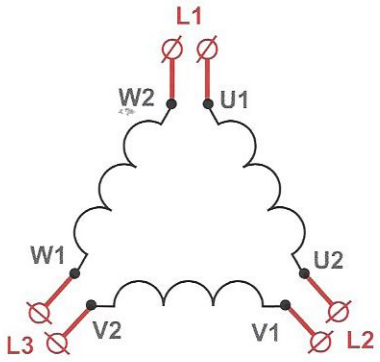
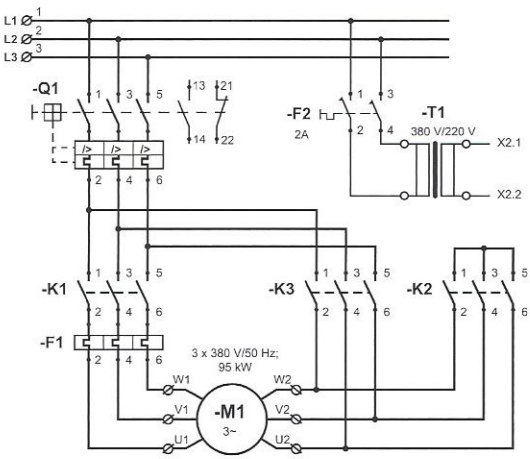


Figure 10.15 – Open terminals

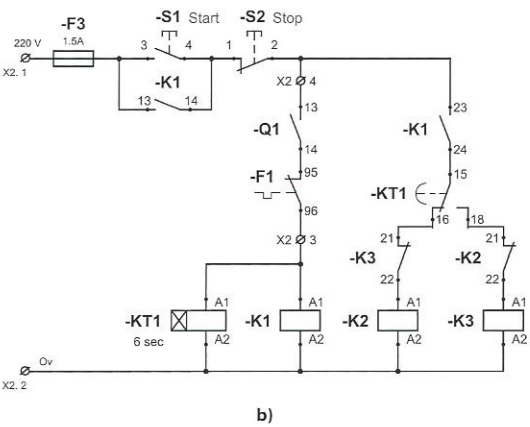
10.3.2 Operation

A Star-Delta starter, such as the DOL starter, has two distinct circuits, a power circuit and a control circuit.

The power circuit, Figure 10.16a, consists of a three-phase power supply, automatic circuit-breaker -Q1, overload relay -F1, line contactor -K1, star contactor -K2 and delta contactor -K3. The control circuit is shown in Figure 10.16b.



a)



b)

Figure 10.16 – a) Star-Delta starter power circuits
b) Star-Delta starter control circuitry

Two of the contactors are closed during the initial run time, delta connection. These are the Main Contactor -K1, alternatively called the Line Contactor, Neutral Contactor or N-contactor and the Delta Contactor -K3. A third contactor, the Star Contactor

- K2, only carries star current when the motor is operating in star mode. The star current is one third of the current in delta connection, by starting in star the inrush current, which is five to seven times that of the nominal motor current is reduced.

Switching on the -Q1 and –F2, power circuit, applies power, 220V AC, across the start button terminals S1/3-4 and across the hold in contacts K1/13-14. Therefore, when the –S1 start button is pressed:

1. The circuit to the –K1 contactor coil closes and –K1 is energised.
2. Line contactor -K1 closes beside the main contacts (1-2, 3-4, 5-6) and the auxiliary contacts 13-14 hold in the coil.
3. -K1 contacts 23-24 apply power to the circuit of the –K2 star contactor.
4. -K2 energises and the motor starts in the star configuration.
5. The star contactor –K2 beside the main contacts (1-2, 3-4, 5-6) will open the auxiliary contact 21-22 interlocking circuit of the –K3 delta contactor coil which prevents simultaneous closing of both –K2 and –K3.

As power is applied across the Delay-On timer, –KT1/A1-A2, star-delta transition timing begins. Timing control of the contactors' changeover is managed by the delay-on time relay -KT1's changeover contacts 15-16-18. Until the preset time delay elapses (six seconds), NCTO contact 15-16 is closed, allowing the motor to accelerate. Once the time delay elapses, the –KT1 contact 15-16 opens, de-energising the –K2 star contactor, this in turn closes the interlocking contact for the –K3 coil. The –KT1 contact then changes over, 15-18 closes, allowing the current to pass through the coil of the Delta contactor –K3. –K3 closes its main contacts (1-2, 3-4, 5-6), changing the motor to the Delta configuration. Meanwhile –K3 contact 21-22 opens, interlocking the circuit of the –K2 coil.

In effect, four states are recognised:

- Off State - all contactors are de-energised (main contacts are opened)
- Star State - the main contactor -K1 and star contactor K2 are energised, delta contactor K3 is opened. The motor is connected in star and one third of the current is used
- Open State - the main contactor K1 is energised while both K3-delta and K2-star contactors are open. This intermediate state occurs while time relay KT1 contacts changeover from 15-16 to 15-18 taking approximately 50 msec. The only voltage that is applied is across the beginnings of the motor windings (U1-V1-W1) while the ends are opened
- Delta State - the K1-main contactor and K3-delta contactors are closed, the K2-star contactor is open. The motor is connected to the full line voltage this means that full power and torque are available.

This type of operation is called open transition switching as it is an open state between the star state and delta state.

10.3.3 Star-Delta Starter Variations

Although control circuits vary, there is no difference between the power circuits of star-delta starters that are made by different manufacturers. The difference results in transition timing, which can be performed either by pneumatic timing modules, electronic timers or by programmable logic controllers (PLC).

The following is a sample of a PLC-based star-delta for the Krupp 45t crane's 160kW main motor. Figure 10.18a illustrates the power circuit. There are only two contactors used for star-delta starting: -K2 is the star contactor and -K3 is the delta contactor. A three-phase 380 V main power supply is applied across the motor's winding terminals U1-V1-W1.

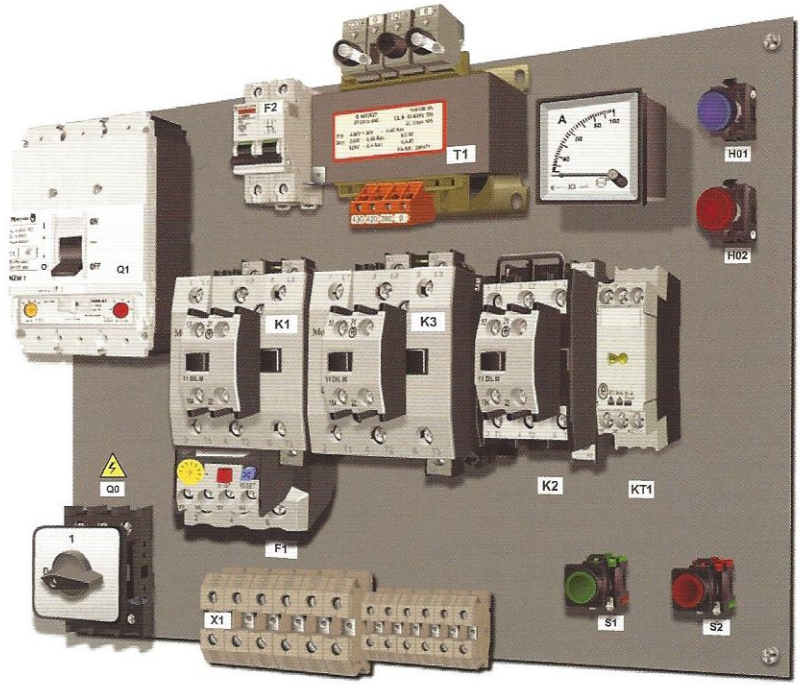
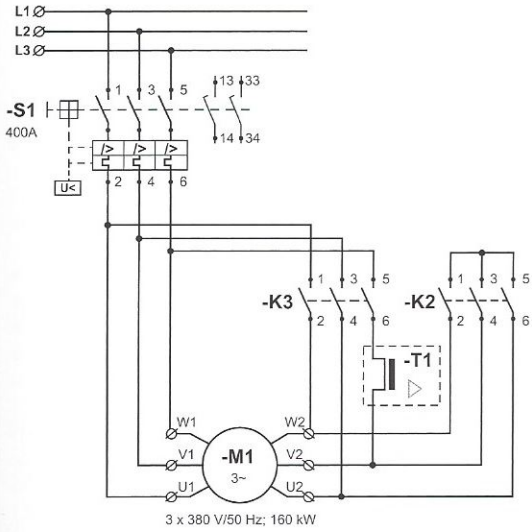
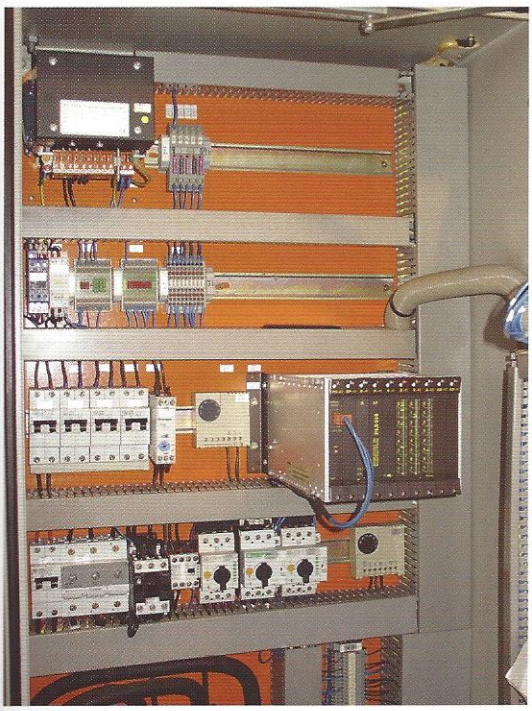


Figure 10.17 – Star-Delta starter interactive simulator

Energising only the contactor -K2 engages the star connection creating a bridge across the motor's winding ends (U2-V2-W2). Once the preset time delay elapses –K2 will open and –K3 closes, applying voltage across the motor's winding ends (U2-V2-W2) and changes the motor to delta configuration. The motor's overload protection is managed by the –T1 current transducer as well as the PTC relay (PTC probes are not shown).



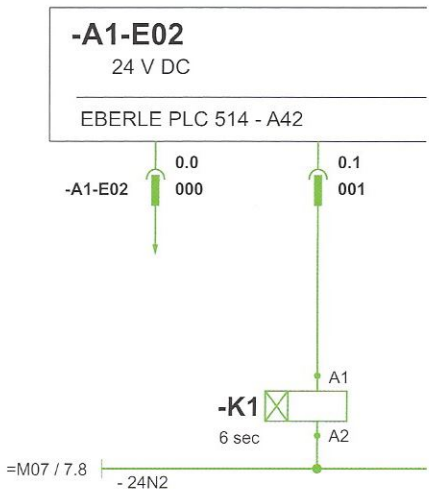
a)



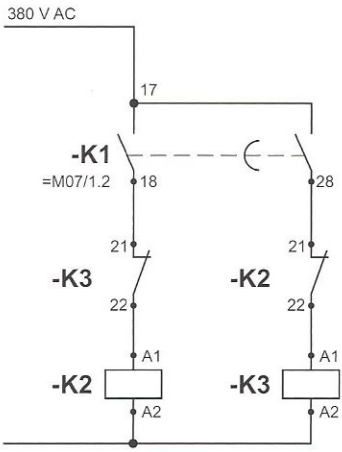
b)

Figure 10.18 – (a) Krupp crane Star-Delta starter (b) Control cabinet overview

The control circuit is illustrated in Figure 10.18. When power is applied to the crane's starter, if there are no critical alarms from the processor module (Figure 10.18 b), the starter is ready to operate. When the start button is pressed, an output signal, 24V DC, is produced by the EBERLE 514 processor's digital output card –A1-E02 in channel 0.1. Voltage is applied across the A1-A2 terminals of the star-delta timer -K1 (Figure 10.19a), instantly closing the contact 17-18 (Figure 10.19b), holding it closed until the preset time-delay (six seconds) elapses. The star contactor -K2 energises the motor connected to the star configuration. Once the time delay elapses, -K1/17-18 will open, achieving the interval-on timing for the first group of –K1 contacts, NOTC contact 17-28 closes, energising the contactor -K3 and connecting the motor to the delta configuration.



a)



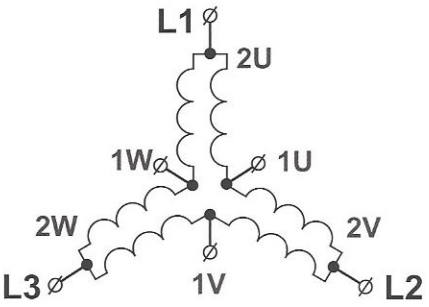
b)

Figure 10.19 – (a) Starting signal from EBERLE PLC output card A42 (b) Starter control circuits

Star-Delta timing is performed by –K1 timer's contacts 17-18, 17-28 as explained in Chapter 7.

10.3.4 Delta-Double Star, Star-Double Star-Delta Starters

The variety of winding connections demand a variety of starters. The Delta Double-Star (Δ/YY) double pole motor winding is shown in Figure 10.20. These motors are widely used as two-speed motors for a variety of electric gear on ships including mooring winches and two-speed pumps. Care should be taken to ensure they are not confused with star-delta starters, as Δ/YY motors run low speed by delta connection and high speed as double star.

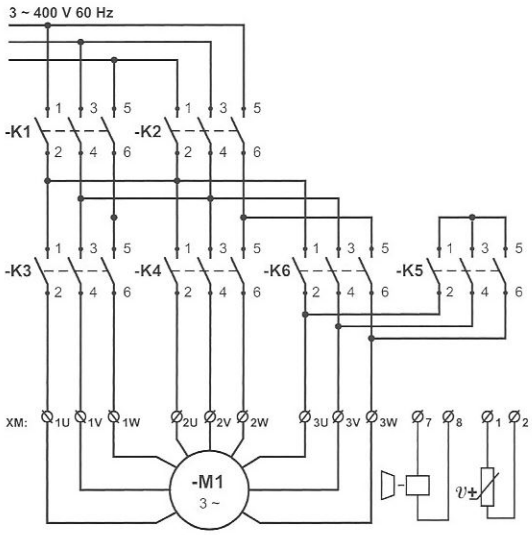


Speed	L1	L2	L3	Terminals	Configuration
High	2W	2U	2V	1U, 1V, 1W join	2WYE
Low	1U	1V	1W	2U, 2V, 2W open	1 DELTA

Figure 10.20 – Delta-Double star e-motor features

The common abbreviation used to define the Delta-Double Star e-motor is Δ/YY. However, there are other versions, for example D/SS used by HATLAPA.

Starters serving such multi-pole motors need 2-6 contactors to be engaged, depending on whether a reverse function is required and how many different speeds are utilised. An example of a 3-speed mooring winch star/double star/delta starter is shown in Figure 10.21.



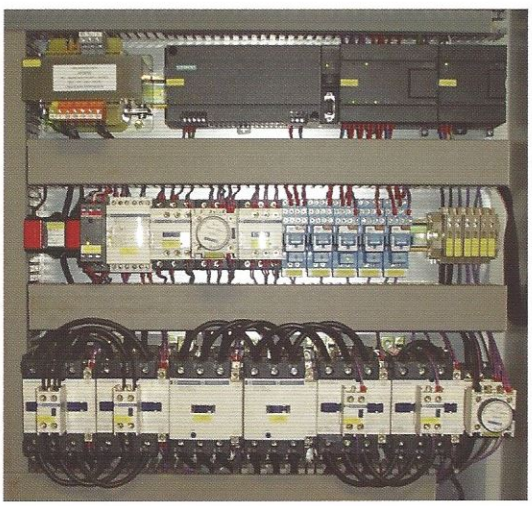


Figure 10.21 – HATLAPA mooring winch's Siemens Simatic S7 PLC-based starter

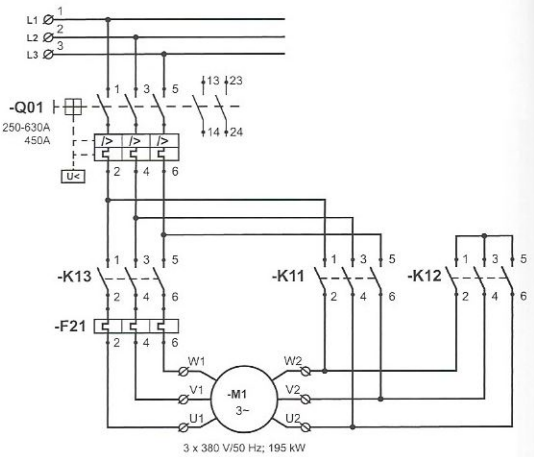
10.3.5 Star-Delta Starter Examples

It is useful to study the following diagrams from live installations. They represent cargo crane star-delta starters from Liebherr, NMF and TTS-LMG applications.

Liebherr 45t Crane 195 kW Motor Starter Control

The S-D Motor starter power circuits, as seen in Figure 10.22, consist of three contactors -K11, -K12, -K13 and overload relay -F21. As -K13 main contacts (1-2, 3-4, 5-6) connect the voltage across the motor's stator winding beginnings U1-V1-W1, it is the neutral contactor. As the -K11 main contacts (1-2, 3-4, 5-6) connect the voltage across the motor winding ends U2-V2-W2, it is the delta contactor. Contactor -K12, which performs as a bridge across the motor winding ends, is the star contactor.

A star-delta starting sequence begins with energising contactors -K13 and -K12, which perform a star-configuration, and once the pre-adjusted time gap has elapsed, the transition from -K12 to -K11 initiates the delta-configuration. The neutral contactor -K13 remains closed for both modes.



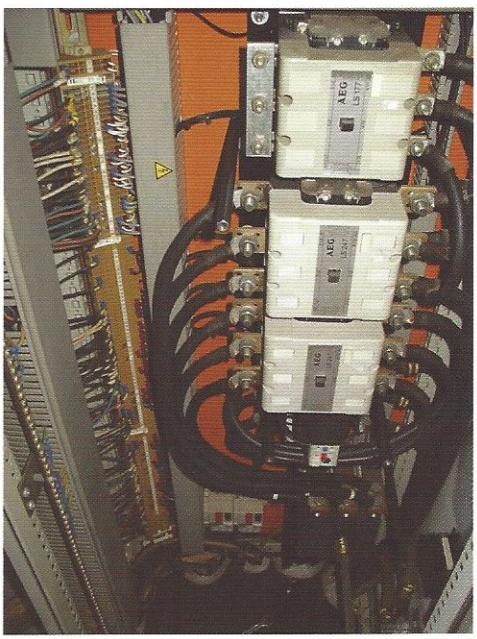


Figure 10.22 – Liebherr 45t crane 195 kW motor starter power circuits and cabinet parts overview

Figure 10.23 represents what starters the control circuitry consists of:

- -K14 - on off delay timer
- contactor coils -K11 and -K12, these are interlocked with each other by the auxiliary contacts 21-22
- -K13 hold-in contacts 13-14 connected in parallel with -K12/13-14.

The path of the ingress current determines the auxiliary relay –K09/13-14 contact, where there is a potential difference of 110 V AC after the control circuit is connected to the supply voltage. When this particular relay is energised, the starting sequence will begin.

Figure 10.24 illustrates the crane's motor start-stop and safety circuit, consisting of:

- -F21 overcurrent relay NC contacts 95-96
- -F25 PTC relay NO contacts 23-24
- -K32 off delay timer NOTO contacts 15-18
- -S11 pushbutton stop NC contacts 21-22
- -S10 pushbutton start NO contacts 13-14.

From a practical point of view, another current path (circuit) is defined, the potential difference 110V AC appears across both –S10 pushbutton terminals 13-14, –K09 relay hold in contacts 43-44. This test, if carried out while troubleshooting, would determine if the entire safety circuit is closed and when starting becomes available.

For a potential difference to exist across –S10 pushbutton terminals 13-14, –F25 PTC relay must close contacts 23-24, the –K32 off delay timer must also close the NOTO contacts 15-18.

On pressing the –S10 push button, the current path will close and relay –K09 will energise, holding-in contact 43-44. The -K09 contact 13-14, Figure 10.23, also closes allowing the current to pass through another circuit energising the star-contactor -K12 coil. The following contacts of -K12 change their status:

- 21-22 opens, interlocking the circuit of delta-contactor -K11
- 13-14 closes, allowing the current to pass through the coil of neutral contactor -K13. -K13 energises while holding in its coil with contacts –K13/13-14.

On energising contactors -K12 and -K13, their main contacts (1-2, 3-4, 5-6) will close applying voltage across the stator's winding terminals (U1-V1-W1) and connecting the other side of the motor winding (U2-V2-W2) into a common star point. The motor starts in the star-configuration, see Figure 10.22.

As K09 energises, its closed contacts 13-14 allow the current to pass into another circuit where the -K14 timer is connected. -K14 is an on-off timer with a pre-set time gap of five seconds. This means that contact 15-16 remains closed (starter connected in star) until the time gap elapses. After five seconds -K14/15-16 will open, disconnecting the coil of the -K12 contactor and de-energising -K12. The following changes will quickly occur:

- Main contacts (1-2, 3-4, 5-6) will open, disconnecting the common star-point from the motor winding ends (U2, V2, W2)
- 21-22 will close interlocking the contacts, preparing the circuit of the delta-contactor coil -K11 for operation
- contacts 13-14 open. The -K13 contactor coil will remain energised via its hold-in contact 13-14, which will remain closed.

While the –K14 timer operates, contact 15-18 closes. Current then flows through the coil of –K11 delta contactor (A1-A2) and -K11 is energised. The main contacts (1-2, 3-4, 5-6) close, connecting the power supply across the motor winding ends (U2-V2-W2), the motor changes over to the delta configuration. The -K11 contactor also operates the auxiliary contacts 21-22, interlocking star contactor –K12.

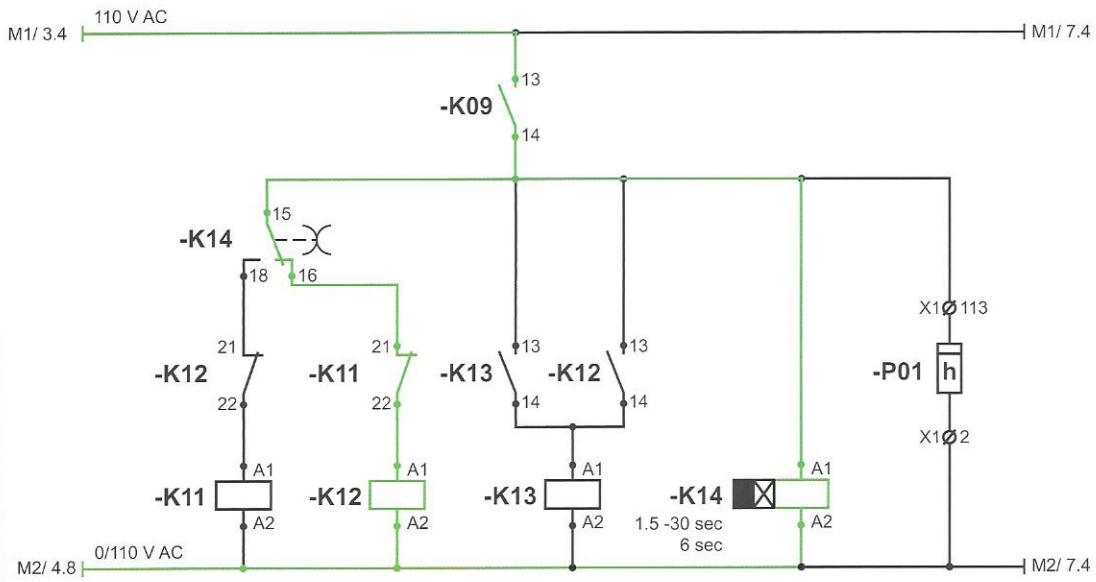


Figure 10.23 – Liebherr 45t crane 195 kW main motor S-D starter control circuit

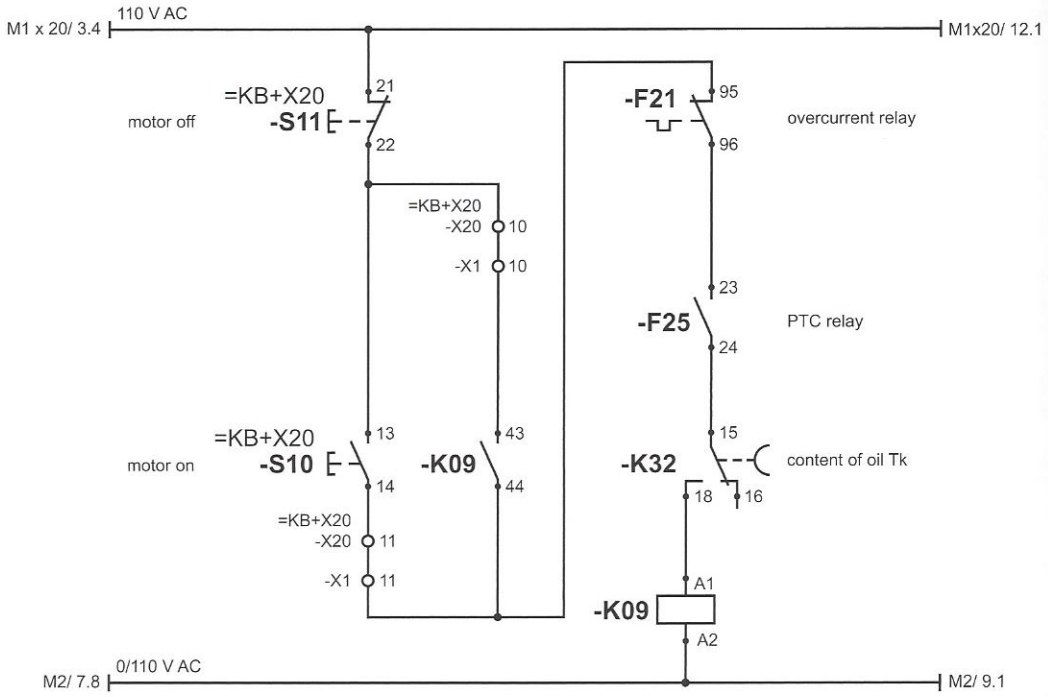


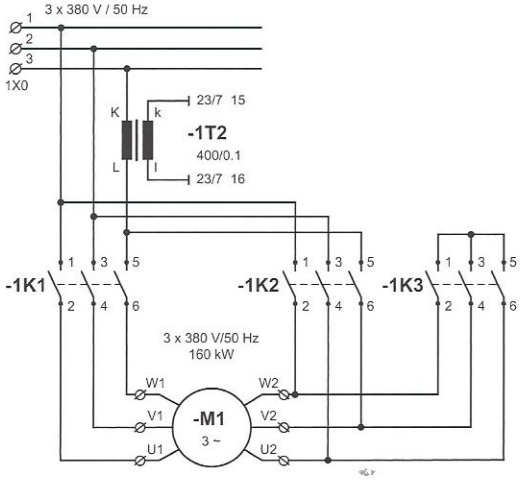
Figure 10.24 – Liebherr 45t crane 195 kW main motor star-delta starter safety circuits

NMF 45t Crane 160 kW Motor Starter Control

The starter power circuit of an NMF 45t crane's main motor is illustrated in Figure 10.25. It consists of three contactors:

- -1K1 - neutral contactor
- -1K2 - delta contactor
- -1K3 - star contactor.

The star-delta starting sequence begins by energising -1K1 and -1K3, operating the star configuration. Once the pre-set time gap transition from -1K3 to -1K2 has elapsed, it will initiate the delta configuration. The neutral contactor -1K1 remains closed in both configurations and the current transformer -1T2 is used for protection, interconnections with monitoring the analogue module are not shown. Overload protection is managed by PTC probes which are not shown here.



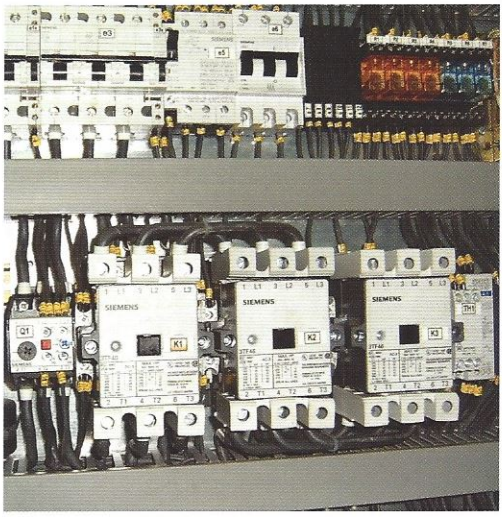


Figure 10.25 – NMF crane motor starter power circuits and overview of cabinet parts

Figure 10.26 illustrates a starter control circuit, features are:

- Contactor coils of star (-1K3) and delta- (-1K2) contactors are electrically interlocked by their auxiliary contacts, 21-22
- there is no time relay for star-delta transition, the entire starting sequence depends on energising the miniature relays -1K7, -1K8 and -1K9, whose changeover contacts (CO) are connected with the contactors' coils
- the control circuit depends on the -1A0 contacts status (emergency stop relay), which is another electrical interlock that monitors the emergency stop buttons.

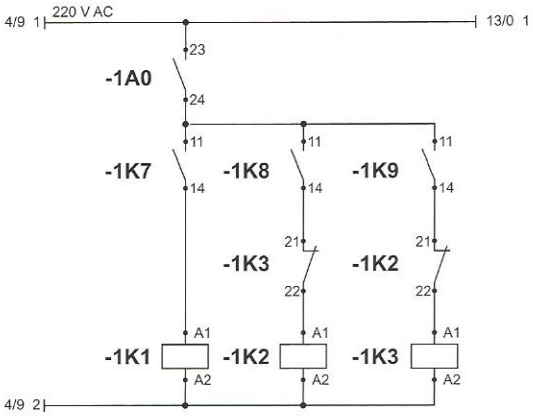


Figure 10.26 – NMF crane main motor starter control circuits

As the control circuit's operation depends on -1A0 contact 23-24, Figure 10.27 should be explored to figure out the pre-requisites for allowing a start to take place.

Figure 10.27 shows -1A0 closes its contacts (23-24) if:

- The power supply 230 V AC is applied across the -1A0/A1-A2 terminals
- S22-S33 loop is closed, all the emergency stop buttons' NC contacts are closed.

Closing auxiliary contacts –1AO/23-24 23-24 completes a current path circuit for the starter's control. The potential difference can now be measured across each CO contact 11-14 of the -1K7, -1K8, -1K9 miniature relays.

As mentioned earlier, no time relay is used in the star-delta transition. Instead, the starting sequence will depend on energising miniature relays -1K7, -1K8, -1K9, whose CO contacts 11-14

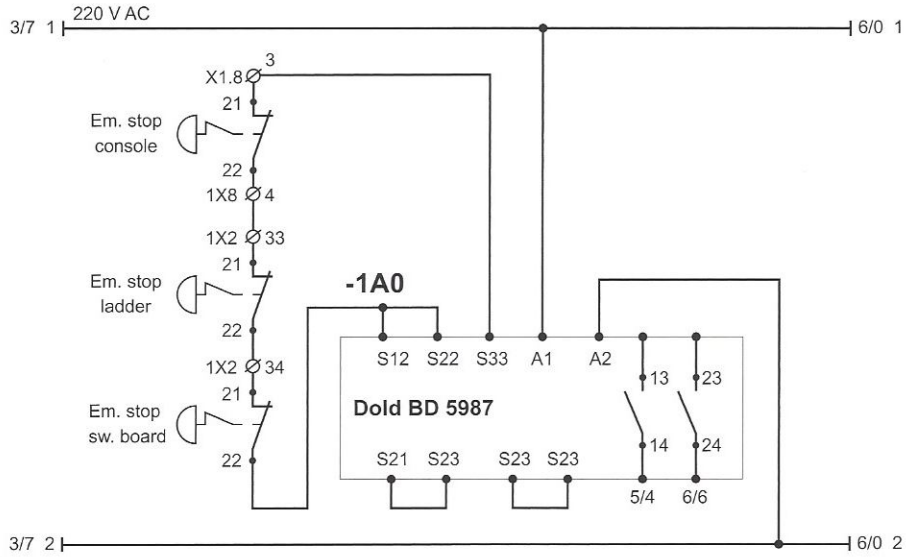


Figure 10.27 – NMF crane 1A0-Emergency stop relay's circuits

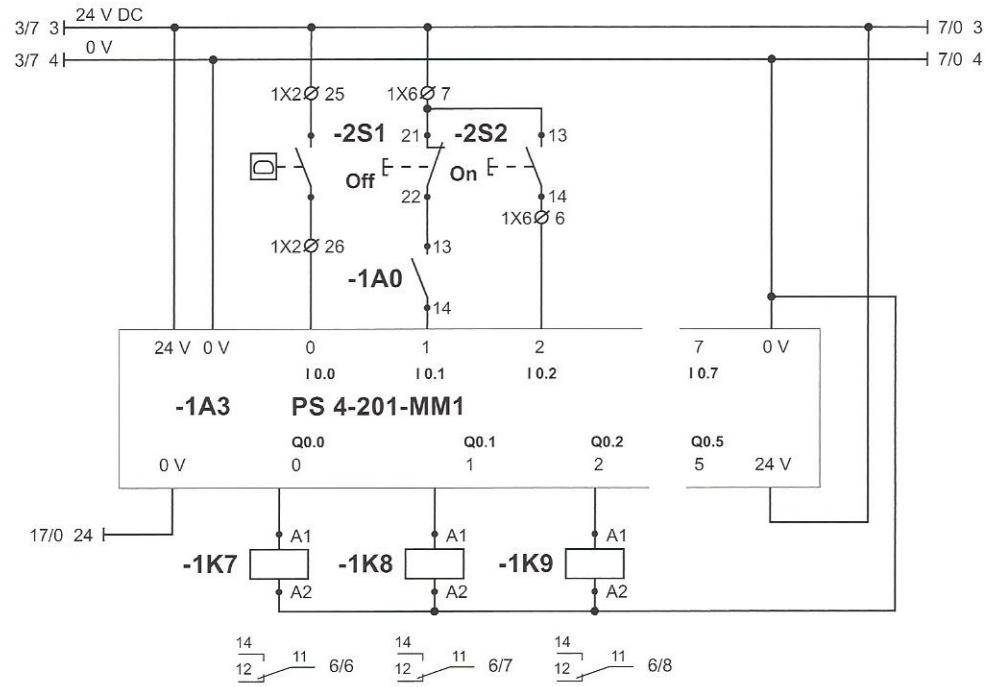


Figure 10.28 – NMF crane PLC input-output module -1A3

are connected in series with the contactor coils as shown in Figure 10.26. Figure 10.28 represents the connections to the -1K7, -1K8 and -1K9 coils.

The Kl Moeller PLC, used for starting and control purposes, consists of connected in-network PS4 input-output modules, one of which, -1A3, is detailed in Figure 10.28.

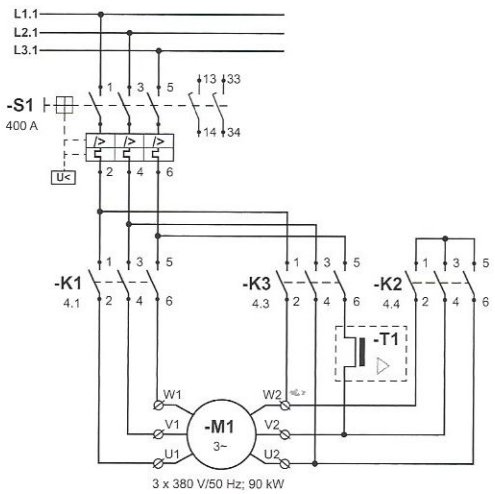
The motor starts once button -2S2 is pressed, there is a digital input at -1A3/I0.2. The -1A3 PS4 module produces an output at Q0.0 and Q0.2 (24V DC), energising miniature relays -1K7 and -1K9 coils. Their CO contacts (11-14) close, applying voltage across the coils of -1K1 (neutral contactor), -1K3 (star contactor) and the motor starts in a star-configuration. The interlocking contact -1K3/21-22 opens, breaking the circuit of the -1K2 delta contactor's coil.

The time delay between the star and delta configurations is achieved by the -1A3 setup, preset by the manufacturer and cannot be altered. Once the time gap has elapsed, the -1A3 module stops output Q0.2 de-energising the relay's -1K9 coil. Contacts 11-14 open, cutting the supply voltage to and de-energising the -1K3 contactor coil, this disconnects the motor's winding end from the common star-point by opening its main contacts. In the meantime, -1A3 output Q0.0 continues, -1K7 remains energised and holds contacts 11-14 closed supplying the coil of the -1K1 neutral contactor. The interlocking contact -1K3/21-22 closes. Once an output at Q0.1 is produced by -1A3, -1K8's miniature relay is energised, closing contacts 11-14, as seen in Figure 10.28, completing the current path of the –1K2 delta contractor.

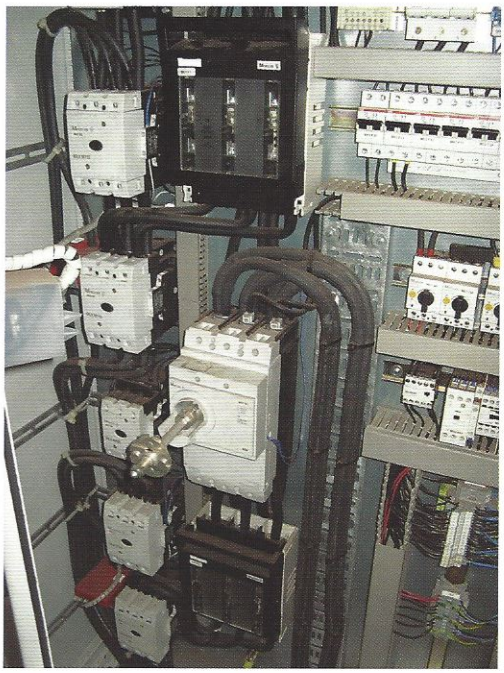
TTS-LMG 250t Crane Motor Starter Control

A 250t TTS-LMG crane has two identical starters, each intended for a 90kW e-motor and consisting of three contactors, ie main contactor –K1, star contactor –K2 and delta contactor –K3, see Figure 10.29a. The star-delta starting sequence initiates -K1 and -K2, performing the star function, once the pre-set time delay elapses it changes over to -K3, performing delta-configuration. The main contactor -K1 will remain closed for both modes.

The motor's overload protection is provided by -T1, a current transducer, as well as PTC probes, these are not shown in Figure 10.29.



a)



b)

Figure 10.29 – (a) TTS-LMG 250t crane starter power circuits for Motor 1 (b) Starter cabinet overview

Figure 10.30 illustrates the motor 1 starter control circuits, motor 2 starter control circuits are identical.

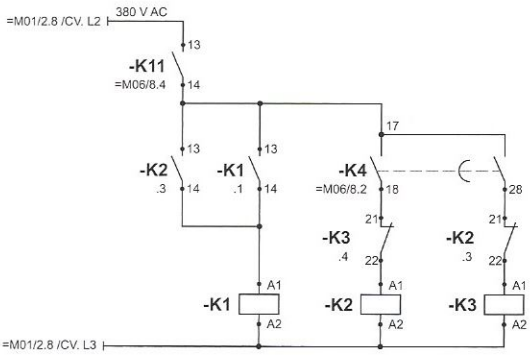


Figure 10.30 – Motor-1 starter control circuits

As the –K11/13-14 contact is connected in series with the entire control circuit, the diagram representing the –K11 coil's connections should be looked at.

Figure 10.31 shows -K11, a feed oil pump contactor, which starts closing auxiliary contacts 11/13-14 as soon the contactor is energised (pump started). This takes place when an input is present at –A5/IX 5.02, ie when the operator switches on the toggle switch –S06, see Figure 10.32, to the 'pump start' position.

Preconditions for starting:

- Power for the crane is switched on
- Ecomat-100 PLC has passed safety and system check-ups with a free of faults status.

Pressing –S06, Figure 10.32, starts the output signal QX 0.05, provided by the –A1 CR0020 module, Figure 10.31. Contactor –K11 energises, starting the oil pump feed, –K11 auxiliary contact 13-14 closes, see Figure 10.30, preparing the control circuit for operation, motor -M1 will start automatically after a 10 second delay, preset by the PLC algorithm.

When an output is produced at –A1/QX 0.04, as seen in Figure 10.31, a voltage is applied across terminals -K4/A1-A2 and the timer will energise, closing contact 17-28 (Figure 10.30) instantly. A current path is introduced through the –K2 star contactor coil and energises it.

In –K2 the:

- Main contacts 1-2, 3-4, 5-6 close, see Figure 10.29, making a common bridge (star point) across the ends of the –M1 motor winding U2-V2-W2
- auxiliary contact 13-14 closes, Figure 10.30, energising the coil of the –K1 main contactor
- auxiliary contact 21-22 opens, interlocking the coil of the –K3 delta contactor.

–K1:

- Closes its main contacts, Figure 10.29, allowing three phase voltage to appear across –M1 winding U1-V1-W1, the motor will start in the star-configuration
- closes auxiliary contacts 13-14, holding-in its coil (Figure 10.30).

The transition time from star to delta will depend on the preset time gap of the –K4 star-delta timer. Once six seconds has elapsed, -K4 will open its contact 17-18, the interval timing for the first group of contacts, de-energising the –K2 contactor which, in turn:

- Opens the main contacts, disconnecting the ends of the –M1 motor from the common bridge
- closes the interlocking contacts 21-22.

The -K4 timer closes its second group of contacts 17-28, allowing the current to pass through the coil of the –K3 delta contactor, this closes the main contacts that apply voltage across –M1 ends U2-V2-W2, changing the motor to delta configuration and remaining in operation during the crane's service.

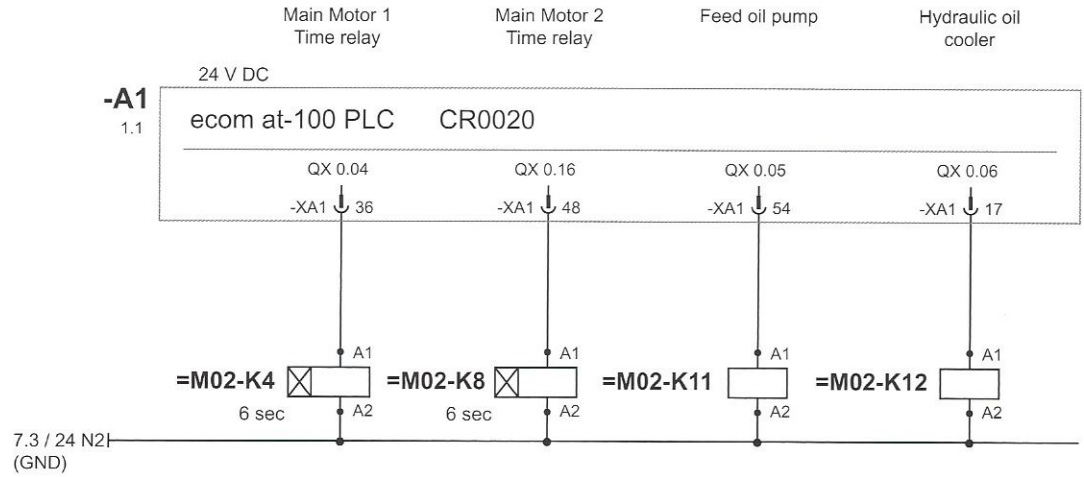


Figure 10.31 – TTS-LMG crane IFM processor output module –A1

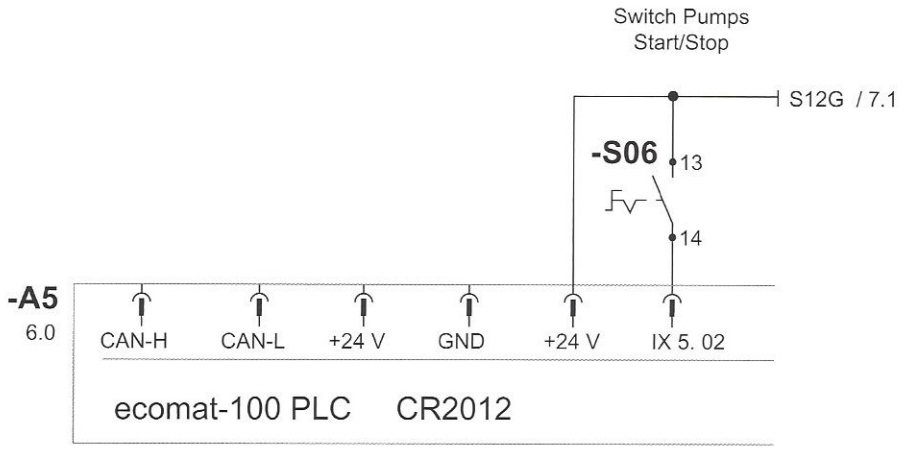


Figure 10.32 – TTS-LMG crane input module –A5

11 Air Circuit-Breakers

11.1 Introduction

An Air Circuit-Breaker (ACB) uses air at atmospheric pressure for arc extinguishing.

ACBs work as switching and current interrupting devices by performing the following two functions:

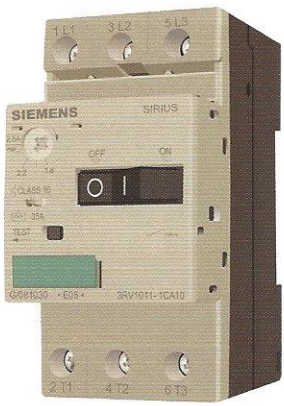
- Switching operations during normal operation and maintenance
- switching operations during any abnormal conditions that may arise, eg overcurrent or short-circuit.

The ACB can be used:

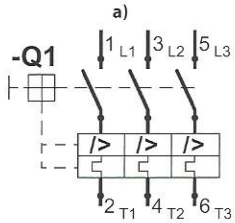
- As infeeding and branch circuit-breakers in three-phase AC distribution systems
- for switching and protecting motors, generators, transformers and capacitors
- as a main switch for all kinds of machinery
- as an emergency stop device, when a circuit-breaker is fitted with an undervoltage release and is used in conjunction with an emergency stop.

11.2 Miniature Air Circuit-breakers

Miniature air circuit-breakers (MCBs) are used widely as protective devices for switching and for the protection of various marine starter applications.



a)



b)

Figure 11.1 – a) SIEMENS Sirius 3RV miniature circuit-breaker b) Diagram's symbol

They replace the conventional fuse-and-switch assembly by providing greater flexibility for operating equipment. During normal operations, they act as a switch but, during overloads or short-circuits, work as a protection device by isolating the faulty section.

The unit incorporates a class 10 or 20 adjustable thermal release that protects the circuit against overload and an instantaneous magnetic-release, intended to protect against a short circuit. Both releases actuate a tripping mechanism, also called a latching mechanism, to trip the breaker. The latching mechanism has a 'trip free' feature ensuring that it cannot be prevented from tripping by holding the operating handle in the 'on' position.

Typical current rating used for MCBs is 1–55 A.

11.3 Moulded Case Air Circuit-breakers

Moulded case air circuit-breakers (MCCB) contain tripping mechanisms and terminal contacts. They are assembled in a moulded case. This adds high dielectric and mechanical strength. In addition, an arc chute is provided which increases the length of the arc and restricts the hot gases that may come into contact with the important parts of the breaker.

They include the following features:

- Normal load current - open and closed switching functions
- protection functions that automatically disconnect excessive overloads and interrupt short circuit currents as quickly as possible
- an indication of the status of the MCCB - open, closed, or tripped.

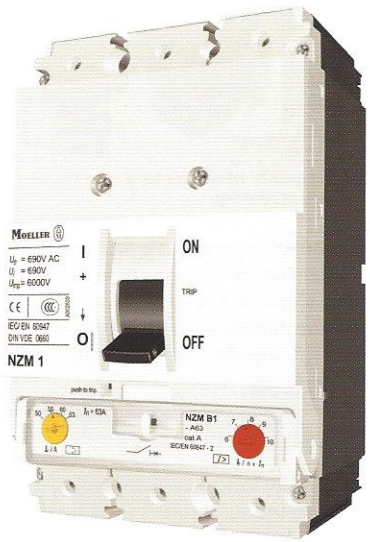
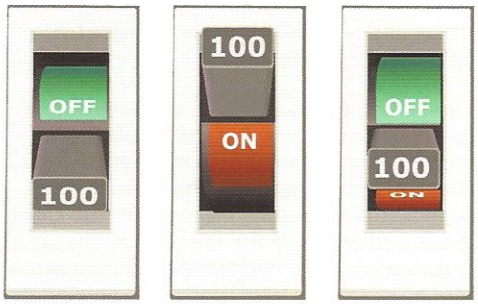


Figure 11.2 – Moulded case air circuit-breaker Kl.Moeller NZM1

In addition to being 'trip-free', a 'quick break' and 'quick make' action is achieved by using a tension spring in the handle. When this moves between on and off, a rapid-contact operating action is produced, irrespective of the speed the handle is moved.

In addition, another important feature to indicating when the breaker is on (in the up position) or off (in the down position), the handle will indicate when the breaker has tripped by moving midway between the two, as shown in Figure 11.3. To reset the system after tripping, the handle must first be moved to 'off' in order to reset the mechanism before being switched to 'on'.



a) Open position b) Close position c) Tripped position

Figure 11.3 – Moulded case circuit-breaker's operating handle positions
This design easily identifies a tripped condition to the operator

MCCBs with ratings up to 3000 A are capable of interrupting currents up to 200 kA and are used for the control of low-voltage marine networks.

A typical MCCB incorporates the components shown in Figure 11.4:

1. Movable contacts assembly
2. Fixed contacts assembly
3. Arc reducing chute with arc splitting grids
4. Latching mechanism
5. Instantaneous magnetic release
6. Terminals.

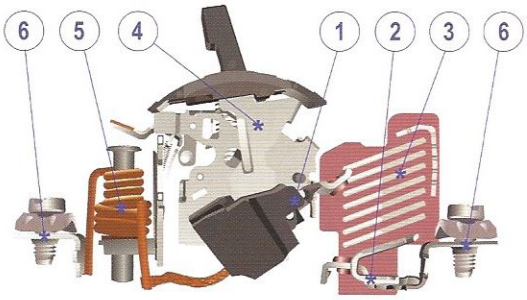


Figure 11.4 – Mitsubishi NF63 moulded case circuit-breaker. Internal components outline

The short circuit action is achieved by the MCCB using an instantaneous magnetic release. If there is a fault, the short circuit current will cause the electromagnet to attract an armature that unlatches the mechanism, tripping the breaker's three poles. The only delay in the action is caused by the time taken for the contacts to physically open and extinguish the arc, normally 20 ms.

To determine how long a breaker will take to trip at a given current, manufacturers provide time-current curves. A time-current curve, see Figure 11.5, is used to show how quickly a breaker will trip at any magnitude of current. The horizontal axis represents current in amps and the vertical axis represents time in seconds.

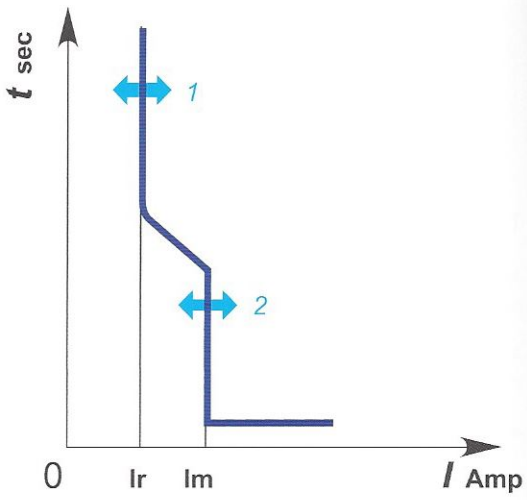


Figure 11.5 – Time-current curve of adjustable circuit-breaker

The top part of the time-current curve (Ir) shows the performance of the overload trip component of the circuit-breaker. The bottom part of the time-current curve (Im) shows the performance of the instantaneous magnetic trip component (short circuit) of the circuit-breaker.

11.4 Automatic Air Circuit-breakers

Automatic ACBs are used in low voltage marine power plants to switch generators and high loads on and off. They are operated either by handle or a motorised remote operation, which is incorporated as a part of the breaker's latching mechanism.

Figure 11.6 is a Siemens 3WS automatic ACB used as a generator breaker.

Depending on the specific equipment, automatic ACBs generally comprise of the component parts which are identified in Figure 11.7.

Figure 11.6 – Siemens 3WS ACB

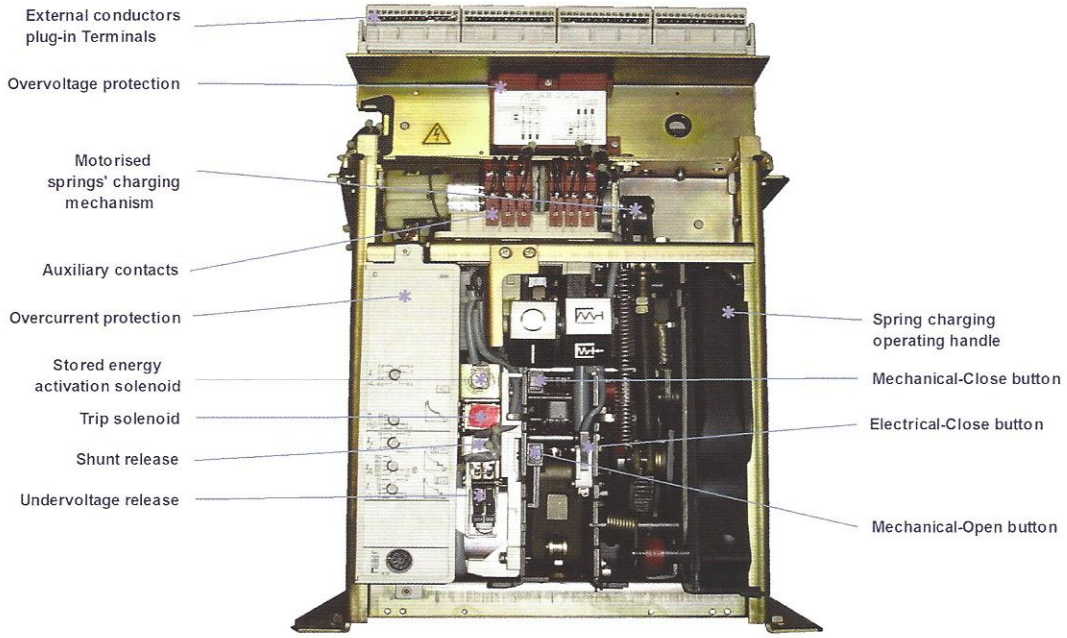


Figure 11.7 – Siemens 3WS version automatic air circuit-breaker internal component parts layout

Depending on the type, ACBs generally comprise the following component parts:

- Basic breakers with moving and static main contact system, charging mechanism, spring storage and handle
- motorised operating mechanism
- closing solenoid system used to switch on the circuit-breaker
- overcurrent protection with tripping solenoid
- auxiliary releases
- auxiliary contacts for internal processes and signalling purposes
- auxiliary connectors.

ACBs are represented in diagrams with a common symbol, as seen in Figure 11.8, which can vary due to additional features added by manufacturers in response to particular requirements.

When studying diagrams, most of the inbuilt ACB features can be identified from the diagram's

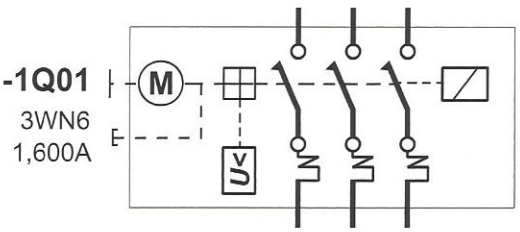


Figure 11.8 – ACB diagram symbol

symbol. The symbol illustrated in Figure 11.8 can be interpreted as follows: -1Q01 is a 3 pole automatic ACB with a motorised spring charging mechanism, hand driven charge, mechanical button close and undervoltage release.

This information is likely to be insufficient for troubleshooting, so the diagram illustrated in Figure 11.9 provides a more detailed overview.

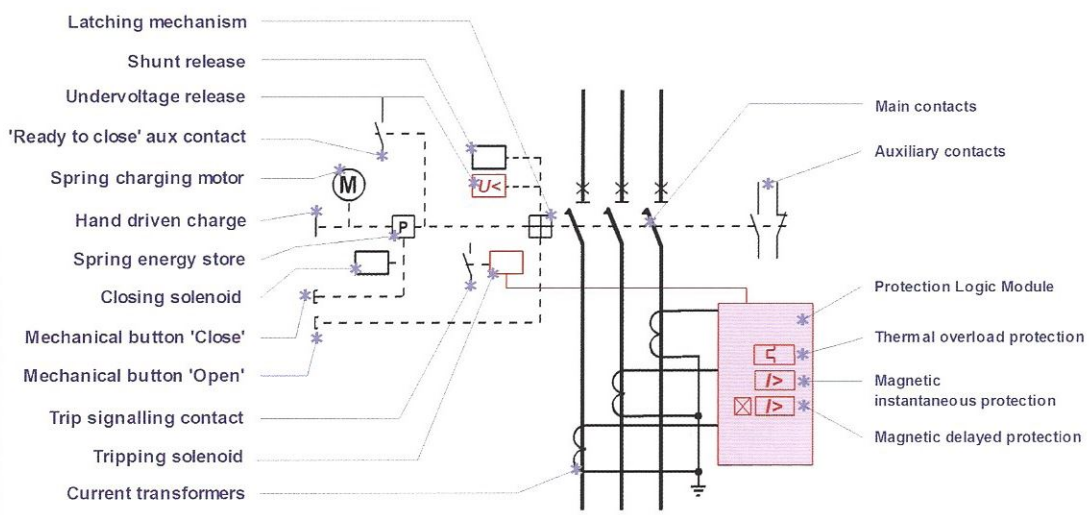


Figure 11.9 – ACB outline

11.4.1 Preconditions for Closing

As an ACB's opening and closing procedures are related to the interconnections between the internal mechanical and electric systems, the required conditions before preparing the breaker for closing (switching on) must be determined. Generally, the conditions are:

- The circuit-breaker is off
- the stored energy mechanism is charged
- the undervoltage release is energised
- the shunt release is not energised
- the closing solenoid is not energised
- any mechanical interlocks are not engaged
- any other interlocks are not activated.

11.4.2 Overload and Short Circuit Protection Adjustment

As previously discussed, time current curves, as seen in Figure 11.10b, are used to show the speed that a breaker will trip at any magnitude of current.

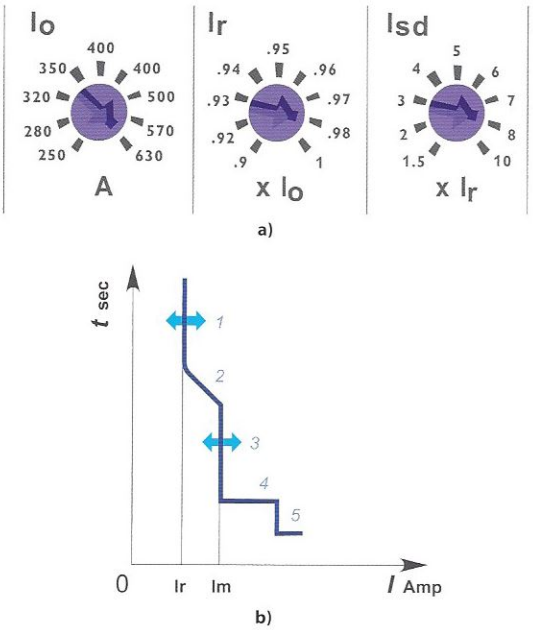


Figure 11.10 – a) Schneider micrologic 2-3
b) Time-current curve adjustment

The following points are illustrated on the curve (Figure 11.10b):

1. Overload protection
2. Long time tripping delay for overload protection
3. Short circuit protection
4. Time delay for short circuit protection
5. Instant short circuit.

The maximum clearing time, ie the time it takes for the breakers to fully open, decreases as the current increases. This is due to the blow-apart contact design which uses the magnetic field that has built up around the contacts, where the magnetic field strength will increase with the current.

Automatic circuit-breakers with electronic trip units have an adjustable overload and instant trip points. Therefore, the greater the fault current, the quicker the breaker will trip.

For the trip unit illustrated in Figure 11.10a, dials Io and Ir adjust the overload protection threshold, while dial Isd adjusts the instantaneous trip for a short circuit.

11.4.3 Undervoltage Release

The undervoltage release is a solenoid that has a magnetic system joined to the ACB's mechanical interlocking system. Figure 11.12 illustrates the undervoltage release used for Siemens 3W circuit-breakers.

It is incorporated for circuit protection purposes as an accessory and opens the circuit-breaker if there is a significant drop in the power supply voltage, less than 0.7Un, or a power supply failure. A circuit-breaker equipped with this protection can only be closed when the undervoltage release is energised and the closing interlock is obtained mechanically.

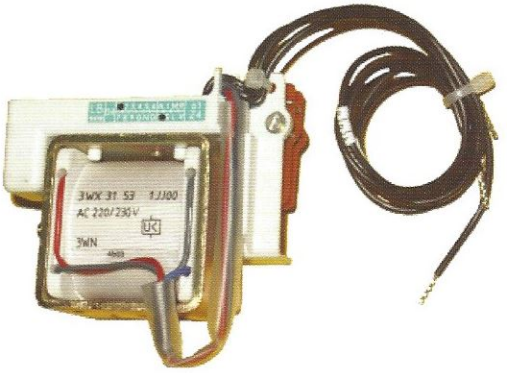


Figure 11.12 – Undervoltage release

For a sequential undervoltage release trip, the circuit-breaker can be closed again, but only if a power supply voltage is applied across the undervoltage release terminals.

The power supply for the undervoltage release is branched on the supply side of the circuit-breaker or from an independent source.

A common international symbol (U<) is used to identify the undervoltage release on diagrams. Undervoltage release terminals have the reference letter D (D1, D2), to help identify them on diagrams, see Figure 11.13.

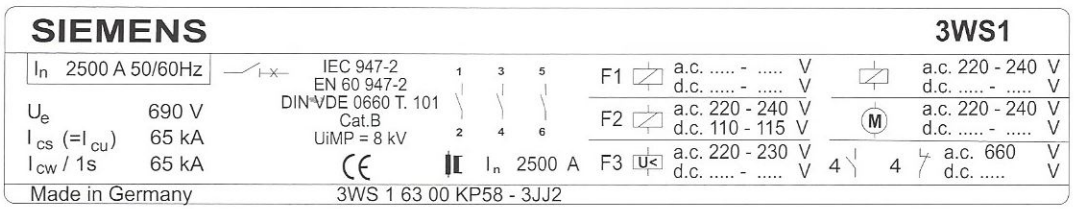

SIEMENS
3WS1
In 2500 A 50/60Hz
IEC 947-2
EN 60 947-2
DIN VDE 0660 T. 101
Cat.B
UiMP = 8 kV
1 3 5
2 4 6
Ue 690 V
Ics (=Icu) 65 kA
Icw / 1s 65 kA
In 2500 A
F1 a.c. ..... - V
d.c. ..... - V
F2 a.c. 220 - 240 V
d.c. 110 - 115 V
F3 a.c. 220 - 230 V
d.c. ..... - V
a.c. 220 - 240 V
d.c. ..... - V
a.c. 220 - 240 V
d.c. ..... - V
4 4 a.c. 660 V
d.c. V
Made in Germany
3WS 1 63 00 KP58 - 3JJ2

Figure 11.11 – Siemens 3WS name plate

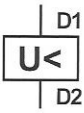
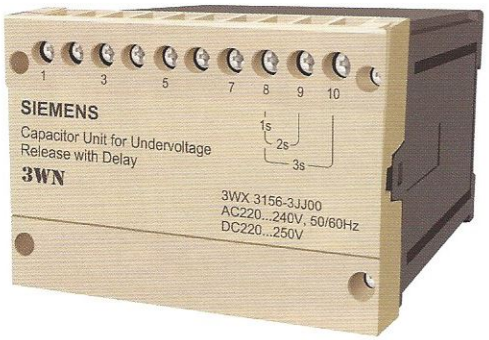


Figure 11.13 – Undervoltage release symbol

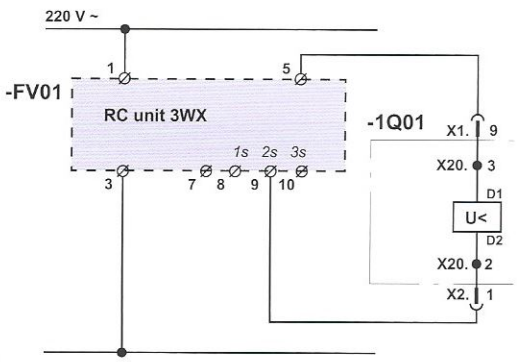
11.4.4 Delay Unit for Undervoltage Release

If there is a temporary voltage failure, such as short voltage dips, it is important the circuit-breakers remain closed. This is achieved by connecting the capacitor delay unit, also known as an RC-unit, in series to undervoltage release circuits. If voltage dips occur, the undervoltage release trips the circuit-breaker after the preset time delay has elapsed. Figure 11.14 represents an RC-unit 3WX from Siemens and its interconnections with Siemens ACB's undervoltage release (U<).

When the power supply voltage is applied across RC-unit terminals 1 and 3, an output voltage appears across common terminal 5 and any of the terminals from 7 to 10. By changing the output terminal, the off-delay time gap can be altered from 0 seconds (7) to 3 seconds (10) in 1 second steps.



a)



b)

Figure 11.14 – a) Capacitor delay unit for undervoltage release Siemens 3WX
b) Interconnections between RC-unit and undervoltage release for 3WS ACB

An RC-unit delay is based on the discharge of internal capacitive circuits. The RC-unit's symbol may be shown on diagrams as an 'off-delay' function block at the side of the undervoltage release symbol (Figure 11.15).

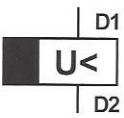


Figure 11.15 – U< release off-delayed

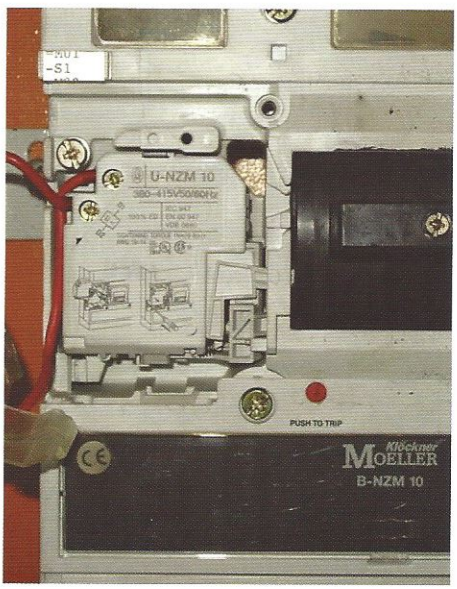
11.4.5 Undervoltage Release Applications

Depending on what the circuit-breaker is to be used for, there are various undervoltage release applications. All applications usually have one thing in common which is the undervoltage release must be energised to allow the circuit-breaker to be closed, complying with class requirements. Undervoltage releases are used in the following operational requirements:

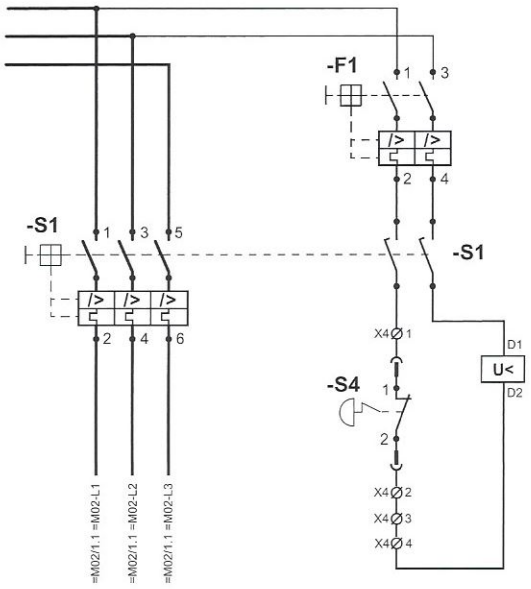
- Emergency stops for power plant, non-essential consumers, eg accommodation ventilation, cargo hold ventilation and reefer sockets
- main switchboard/emergency switchboard transfer line feeder
- generator protection, in conjunction with protection devices, eg over/undervoltage relay, frequency monitoring relay and overcurrent relay
- emergency stop for crane starters
- emergency stop for thrusters
- emergency stop for feeding circuit-breakers related to:
  - boilers
  - fuel transfer and circulating pumps
  - oil transfer and circulating pumps.

The examples below illustrate the various applications met onboard. Figure 11.16 represents the main power supply circuit-breaker for a Krupp crane.

Circuit-breaker –S1 is fitted with an undervoltage release which is connected in series with emergency stop button -S4. Other emergency stop buttons are connected in series via terminals X4 2 through X4 4. On pressing –S4, circuit-breaker –S1 will trip.



a)



b)

Figure 11.16 – a) Krupp crane's main circuit-breaker –S1 (view at undervoltage release)
b) Undervoltage release connective features

Another feature of circuit-breaker –S1 is the early make auxiliary contacts which connect in series with the undervoltage release. This allows the undervoltage to remain de-energised when –S1 is open.

Figure 11.17 represents part of a main switchboard diagram which relates to the generator panel's protection appliances.

Generator circuit-breaker -1Q01 has an undervoltage release connected in series to -1UA16 overcurrent relay and -1UA09 reverse power relay NO contacts. RC-unit -1FV01 provides a time delay for safe operation if there is any voltage drop.

During operation, when under a load, the generator faces either an overload or reverse power situation, the undervoltage release will lose its power supply, tripping the generator's automatic circuit-breaker. If this occurs, the generator breaker can only be closed once the undervoltage power supply has been restored.

Figure 11.18 illustrates an overview of Siemens 3WS circuit-breaker releases, an undervoltage release is on the bottom.

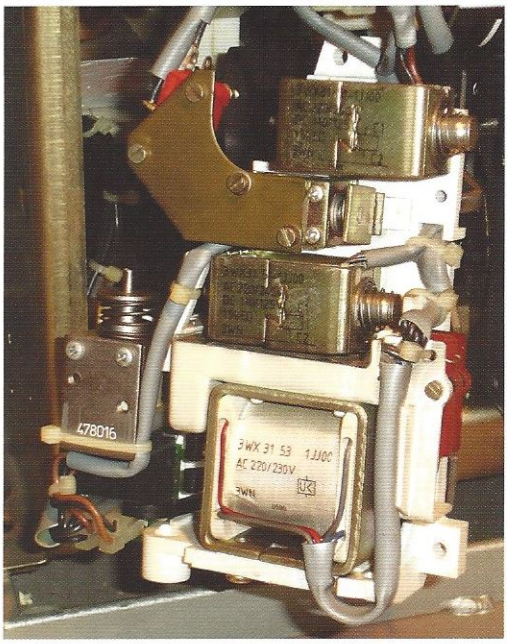


Figure 11.18 – Siemens 3WS breaker. Overview of releases plate

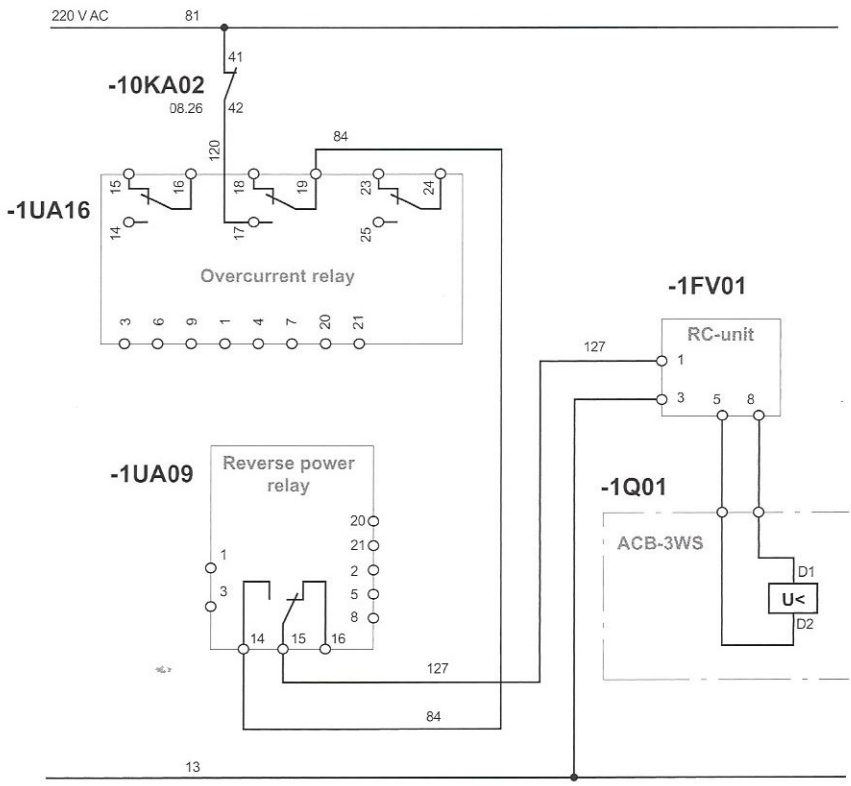


Figure 11.17 – Generator panel protection appliances

11.4.6 Shunt Opening/Closing Release

A shunt release is a solenoid which can be fitted into a circuit-breaker. The terminals are referred to with the letter **C** (C1, C2) as illustrated in Figure 11.19.

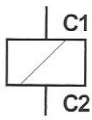


Figure 11.19 – Shunt release

A shunt release allows the switchgear to be opened and closed using a remote control providing instantaneous operation and can be permanently powered.

11.4.7 Overcurrent Release

The overcurrent release system comprises of the following components:

- Current transformers
- overcurrent release
- tripping solenoid
- mechanical re-closing lockout
- tripped signal auxiliary contact.

The signal from the overcurrent release is connected to the tripping solenoid.

Table 11.1 provides an overview of how manufacturers define circuit-breaker releases through their diagrams and manuals.

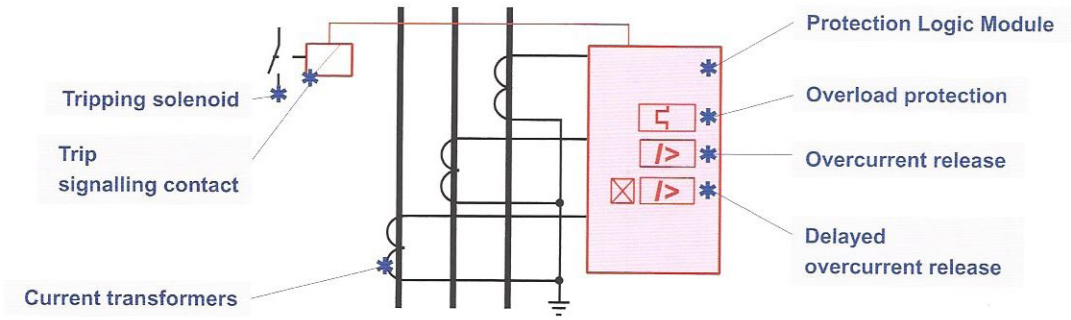


Figure 11.20 – Overcurrent release system

Type of Release/Terminals	ABB SACE E	Siemens 3W	Merlin Gerin Masterpact N	Kl.Moeller NZM
Shunt closing release / C1, C2	YC	Y1	XF	
Shunt opening release / C1, C2	YO	F2	MX	
Instantaneous voltage release (Undervoltage release) / D1, D2	YU	U<	MN / UVR	U<
Delayed voltage release / D1, D2	YU	U<	MN / UVR	U<
Short circuit release	I>	I>>	I>	I>

Table 11.1 – ACB's releases definition

Function	Components
Remote Control	• Shunt opening release • Shunt closing release • Geared motor for automatic charging of closing springs
Remote signalling or actuation of automatic functions depending on the state (open/closed or isolated), or on the position (connected/isolated) of the circuit-breaker	• Auxiliary contacts of circuit-breaker open/closed • Auxiliary contacts of circuit-breaker connected, isolated for test (for withdrawable circuit-breakers only) • Contact for electrical signalling of overcurrent trip units tripped • Contact for signalling undervoltage de-energised • Contact for signalling springs charged
Remote opening for various needs, including: – manual emergency operation – opening interlocked with operation of other switchgear or with plant automation requirements	• Shunt opening or undervoltage release
Automatic opening of circuit-breaker due to undervoltage	• Instant or time delay voltage release. The time-delay device is recommended so that unwarranted operation due to temporary voltage drops can be avoided (for functional and safety reasons) • Contact for signalling undervoltage energised
Mechanical safety locks for maintenance or functional requirements for interlocking two or more circuit-breakers	• Key lock in open position • Padlock device in open position • Key lock and padlock device is connected, isolated for test, isolated position
Automatic switching of power supplies	• Mechanical interlock between two or three circuit-breakers

Table 11.2 – ACB functions

Several of the functions listed in Table 11.2 may be used at the same time depending on the use of the circuit-breaker.

11.4.8 Air Circuit-breaker Control Diagrams

Figure 11.21 illustrates an internal control diagram for a Siemens 3WS circuit-breaker. When analysing the diagram, the major components and their connective terminals that relate to interlocking circuits should be identified. These should be measured first when troubleshooting ACBs related malfunctions.

The Siemens diagram does not use a common symbol for undervoltage release or terminal reference letters. However, as can be seen from the name plate in Figure 11.11, the Siemens reference code for undervoltage is F3. Therefore, the correct terminals for measurements, ie undervoltage release: X1.9, X2.1, can be determined.

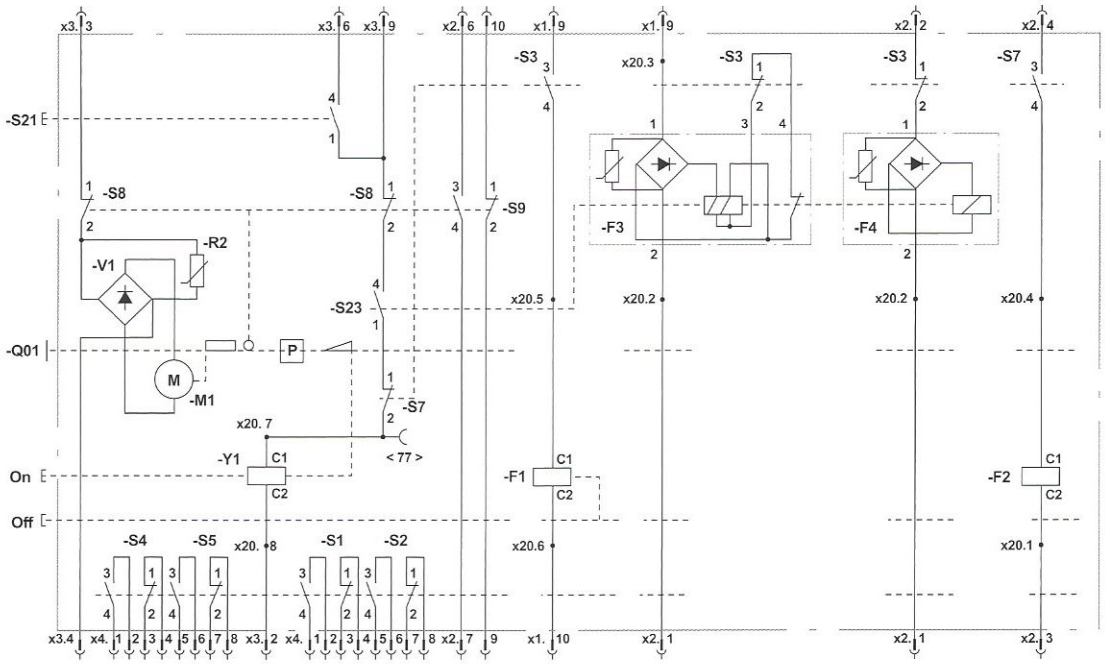


Figure 11.21 – Siemens 3WS control diagram

LV Power Plant, Main Switchboards, Emergency Switchboards and Power Distribution

12

12 LV Power Plant, Main Switchboards, Emergency Switchboards and Power Distribution

12.1 Ship's Power Plant

An average ship may be equipped with two or three main generator sets, typically rated 350 – 1,000 kVA each. During sea passages a ship may use a shaft generator and during blackout situations an emergency generator will supply critical equipment.

When at sea, a ship could be expected to consume around 350 kW, but on some ships, eg carrying reefer containers, the load consumption could be expected to rise over 2000 kW. This assumes that one reefer container consumes on average container 10 kW, the average container ship carries 150 – 250 reefer units. When manoeuvring, power consumption rises. The ship's power distribution is constructed in such a way that the shaft generator busbar can be disconnected from the main busbars by using a bus coupling breaker. This allows a direct feed to the bow thruster from the shaft generator, while other power required for propulsion and manoeuvring is fed from the main busbar.

When in port, power consumption increases due to cargo gear, hatch covers, hydraulic systems and cargo cranes being used. Two or three main generators usually support the ship's consumers unless the ship remains at a lay-by berth.

In the event of a blackout, the emergency generator, which is always in standby mode, starts automatically and will supply the emergency switchboard, supplying essential equipment.

The ship's power network is constructed in such a way that the main switchboard will supply power to both essential and non-essential consumers. The purpose of this is to disconnect the non-essential consumer groups from the busbar in emergency shutdown conditions.

12.2 Power Plant Features

Figure 12.1 is an example of a Low Voltage (LV) ship's power plant which is equipped with a shaft generator (900 kVA), two diesel generators (400 kVA each) and an emergency/harbour generator (400 kVA) connected to relative switchboards.

The power plant consists of two independent switchboards: Main Switch Board (MSB) and Emergency Switch Board (ESB). Under normal conditions, they are joined together by means of MSB-ESB Transfer Line.

12.2.1 Main Switchboard

The main switchboard is a major part of the power plant, consisting of five panels, joined together by main busbars and located in the engine control room. Two 400 kVA generators (G1 and G2) can be connected to the main busbars by ACBs Q1 and Q2. A 900 kW shaft generator (SG) can be connected to the shaft generator busbars (SG busbars) by a circuit-breaker Q4. The main purpose of the shaft generator while manoeuvring is to supply power for the 400 kW bow thruster, while coupling breaker Q3 remains open. During a sea passage, Q3 can be closed to feed the main busbars.

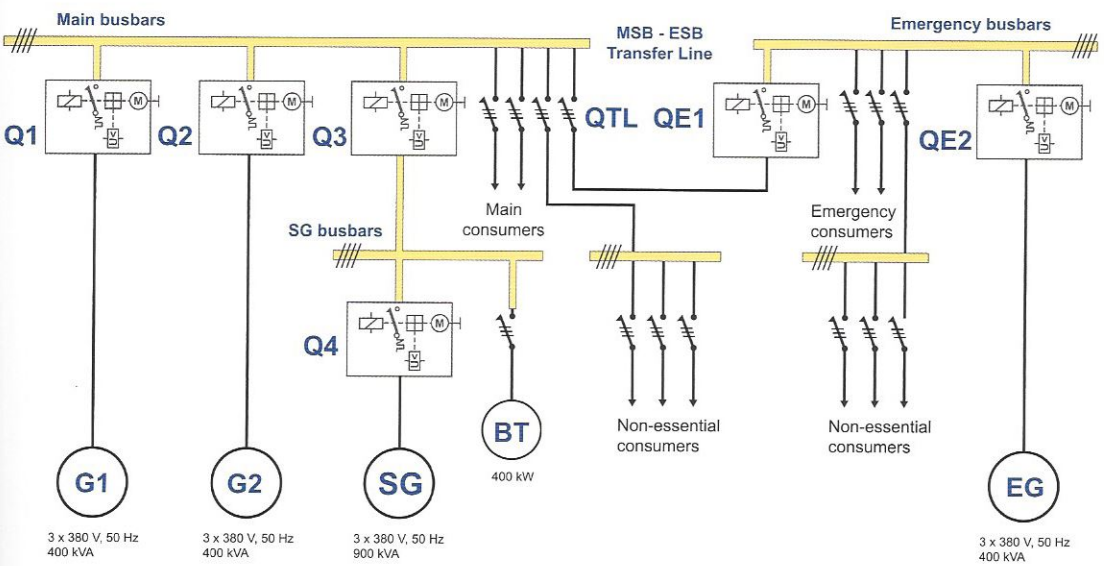


Figure 12.1 – Ship power plant single line diagram

12.2.2 Emergency Switchboard

The emergency switchboard (ESB) consists of three panels, joined together by emergency busbars and is located in the emergency generator room.

The ESB is connected to the MSB by a transfer line, that operates by the two circuit-breakers, QTL and QE1, closing simultaneously.

12.2.3 MSB-ESB Transfer Line

The transfer line, also called a transition line, is a live feeder for power transition between the MSB and ESB. When any of the main generators are on mains, the transfer line is closed, ie QTL and QE1 are closed, supplying the emergency consumers from the MSB.

If a blackout occurs, the transfer line will open, automatically splitting the power plant into two independent sections, main and emergency, achieved by an automatically tripping QE1 circuit-breaker, Figure 12.2.

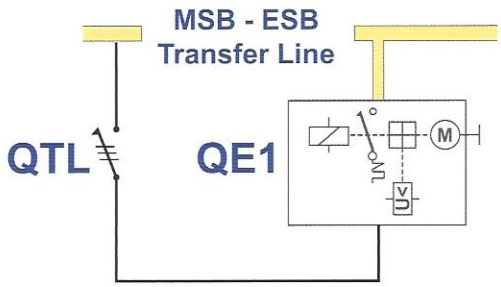


Figure 12.2 – MSB-ESB transfer line outline

The QTL circuit-breaker is located in the MSB panel. It will always remain closed. QE1 is an air circuit-breaker with motorised gears with a spring charging mechanism and an undervoltage release. This trips the transfer line circuit-breaker QE1 if there is a blackout. QE1 is located in the ESB panel.

As seen in Figure 12.3, QE1 CB's undervoltage release is supplied directly from the MSB and is kept energised while the MSB busbars are live. The purpose of the QE1 circuit-breaker undervoltage release(U<) is to monitor the main busbar voltage, tripping QE1 if there is a blackout.

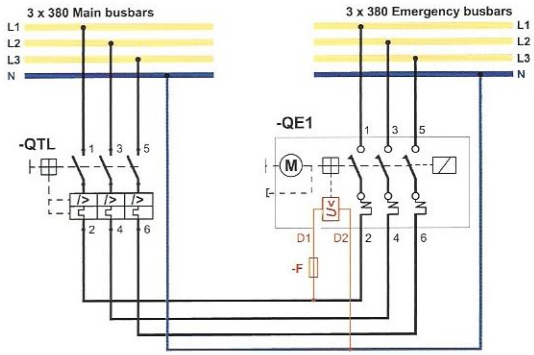


Figure 12.3 – MSB-ESB transfer line undervoltage release wiring features

12.3 Power Management Features

To comply with regulations, the generator circuit-breakers Q1, Q2, Q4, QE2 and coupling breaker Q3, shown in Figure 12.2, are integrated with power management systems. Protection is provided by reverse power relay, undervoltage release, overcurrent relay and frequency control relay as illustrated in Figure 12.4. If a programmable logic control is fitted, the task is managed by PLC logic.

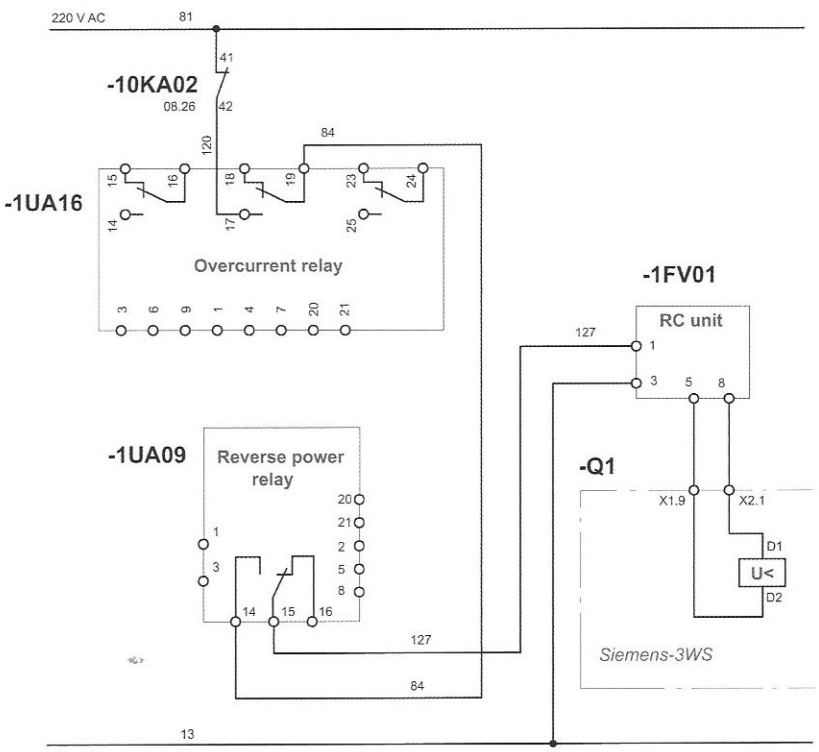


Figure 12.4 – Generator's panel safety application

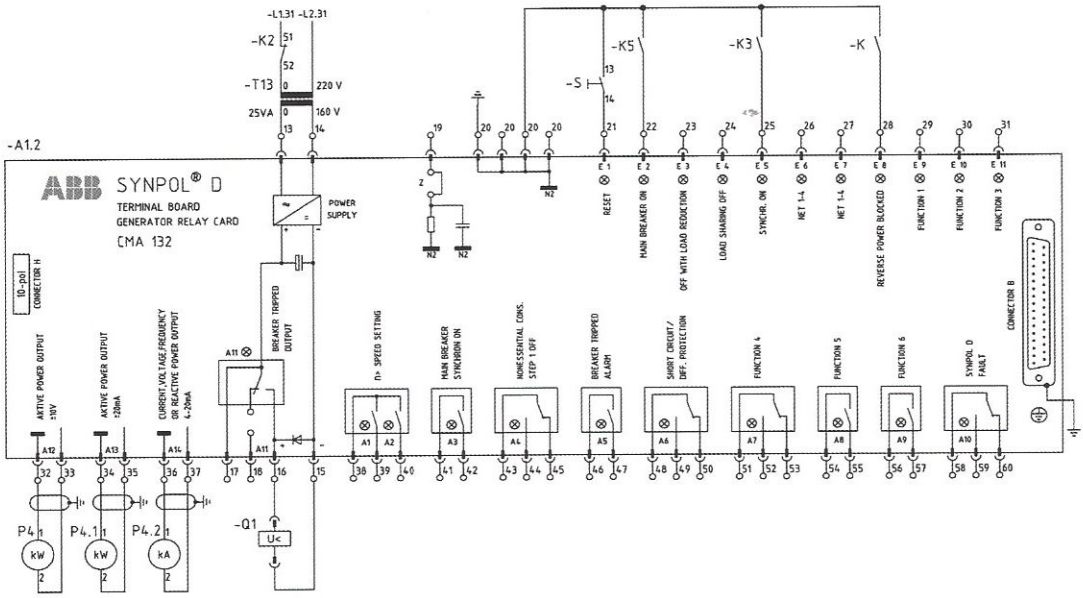


Figure 12.5 – SYNPOL-D PLC generator CMA132 circuit board external connections

Figure 12.5 shows a printed circuit board, CMA 132, as a part of an ABB Synpol-D PLC-based power management system.

The generator circuit-breaker undervoltage release –Ql (U<) is connected via CMA 132's internal output relay contact. The output status is indicated with the corresponding LED. The undervoltage release has a surge protection diode across its terminals and a capacitive filter across the power supply rectifier (~/=). The power supply for an undervoltage release comes directly from the generator, input terminals 13-14. This means that once the primary mover has started and the generator got excited, its automatic circuit breaker is ready to be closed unless an allowance for operation has been received from SYNPOL-D PLC's logic. Then CMA 132 output relay energises, supplying power across U< via CMA 132 output terminals 15 and 16.

Unless the PLC application detects any problems with the generator parameters, CMA 132's output relay contacts will remain closed. Power is then applied to an undervoltage release and the generator will remain in operation. If there is a problem while the generator is live on mains, the output relay opens the contact, de-energising the undervoltage release causing the Q1 generator breaker to trip.

Figure 12.6 represents a SYMAP® controller operator panel. Made by Stucke Elektronik, it provides full style power management for a ship's power plant. Integrated generator protection includes a synchronisation unit, load sharing, frequency controller, voltage regulator, power factor control, load controller, load depending start/stop function, reverse power control, preferential trip management, blackout management and diesel control. In other words, it includes all functions of the SYNPOL®-D System and is intended to be the next generation of ship power management.

Figure 12.7 illustrates features of undervoltage release circuits in relation to the power management system. The power supply for U< (8-9) is connected directly from the generator. The generator breaker will remain closed until PMS logic allows it. The CB will trip or fail to close if the power supply to U< is interrupted.

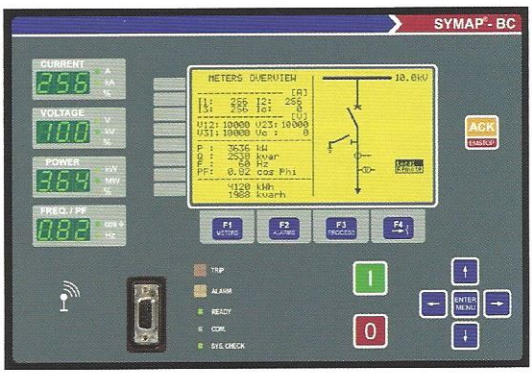


Figure 12.6 – SYMAP® PMS operator panel

12.4 Electrical Enclosures IP Class

Ingress Protection (IP) is a classification of protection indicating the capability of an electrical enclosure to withstand the ingress of particles and liquids.

The designation to indicate the degree of protection consists of the letters IP followed by a two or three-digit code or numerals that indicate conformity with conditions. Tables 12.1 and 12.2 aim to help in decoding the first two digits. The third digit or numeral is often omitted for metal enclosures and is used to indicate the strength of polycarbonate enclosures.

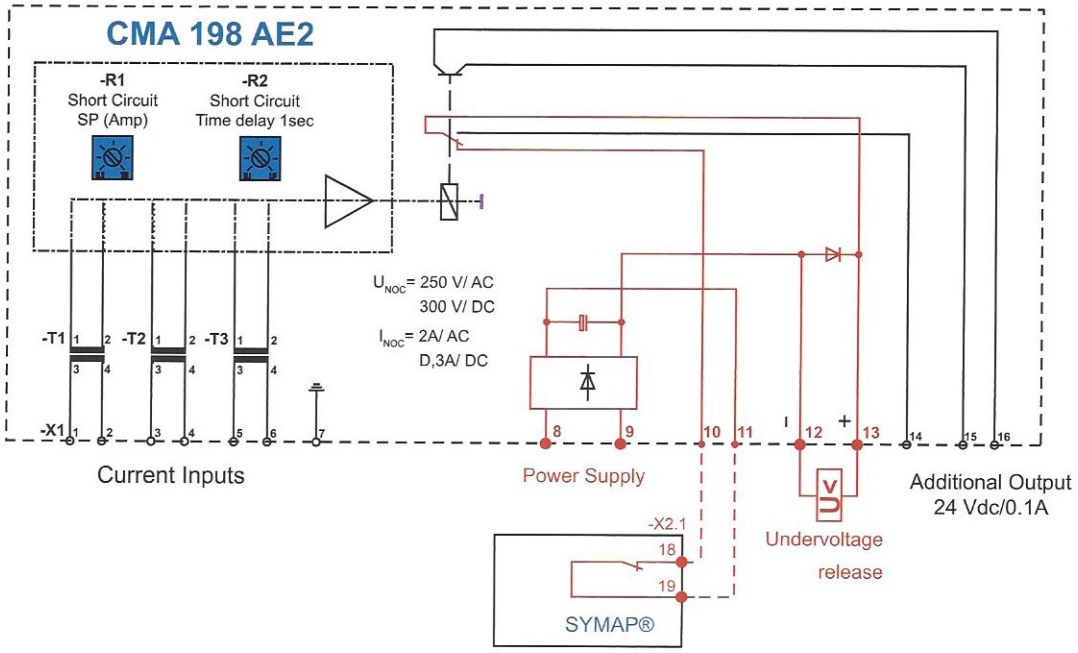


Figure 12.7 – SYMAP® PMS connections to generator circuit-breaker's undervoltage release

Characteristic Numeral	Description	Definition
0	Non-protected	No special protection provided.
1	Protected against solid objects >50 mm	A large surface of the body, such as a hand (but no protection against deliberate access), ie solid objects exceeding 50 mm in diameter have no access.
2	Protected against solid objects >12 mm	Fingers or similar objects not exceeding 80 mm in length, ie solid objects exceeding 12 mm in diameter have no access.
3	Protected against solid objects >2.5 mm	Tools, wires, etc of diameter or thickness >2.5 mm, ie solid objects exceeding 2.5 mm in diameter have no access.
4	Protected against solid objects >1 mm	Wires or strips of thickness >1 mm, ie solid objects exceeding 1 mm in diameter have no access.
5	Dust protected	Ingress of dust is not totally prevented, but dust does not enter in sufficient quantity to interfere with satisfactory operation of the equipment.
6	Dust-tight	No ingress of dust is possible.

Table 12.1 – Degrees of protection (against solid objects) indicated by the first characteristic numeral

Characteristic Numeral	Description	Definition
0	Non-protected	No special protection provided.
1	Protected against dripping water	Dripping water (vertically falling drops) is to have no harmful effect.
2	Protected against dripping water when tilted up to 15°	Vertically dripping water is to have no harmful effect when the enclosure is tilted at any angle up to 15° from its normal position.
3	Protected against spraying water	Water falling as a spray at an angle up to 60° is to have no harmful effect.
4	Protected against splashing water	Water splashing against the enclosure from any direction is to have no harmful effect.
5	Protected against water jets	Water projected by a nozzle against the enclosure from any direction is to have no harmful effect.
6	Protected against heavy seas	Water from heavy seas or water projected in powerful jets is not to enter the enclosure in harmful quantities.
7	Protected against the effect of immersion	Ingress of water in a harmful quantity is not to be possible when the enclosure is immersed in water under defined conditions of pressure and time.
8	Protected against submersion	The equipment is suitable for continuous submersion in water under conditions which are specified by the manufacturer. **Note:** this means that the equipment concerned is hermetically sealed. However, in certain types of equipment, it can mean that water can enter, but only in such a manner that it produces no harmful effect.

Table 12.2 – Degrees of protection (against liquids) indicated by the second characteristic numeral

Example: IP56 – dust and heavy seas protected enclosure

Characteristic Numeral	Description
0	Non-protected
1	Protected against Impact energy equivalent 150 g
2	Protected against Impact energy equivalent 250 g
3	Protected against Impact energy equivalent 250 g
5	Protected against Impact energy equivalent 500 g
7	Protected against Impact energy equivalent 1.5 kg
9	Protected against Impact energy equivalent 5 kg

Table 12.3 – Degrees of protection (against mechanical impact) indicated by the third characteristic numeral

The IP classes in Table 12.4 are examples of some manufacturers' enclosures ratings for marine installations:

IP Rating	Installation Location	Type of Protection
IP14	External installation	Protection against falling rain, no damage from build-up of ice on enclosure.
IP20	Internal installation	Protection against accidental touching of live parts and against ingress of falling dirt.
IP22	Internal installation	Protection against ingress of dropping water and falling dirt.
IP52	Internal installation	Proof against ingress from dropping water and falling dirt, protection against corrosion.
IP54	External installation	Protection against ingress of hail and wind blown dust and rain. External mechanisms remain usable when ice covered.
IP56	External installation	Protection against falling rain, sprayed water and water jets. No damage from ice build up on enclosure, protection against corrosion.
IP67	Internal or external installation	Protection against ingress of water when submerged longer, protection against corrosion.

Table 12.4 – Manufacturers' enclosures ratings for marine installations

12.5 Marine Cables/3M Heat Shrink Cables Repair Technology

Wiring cables form an integral part of the electrical system on board a ship. All cables must be able to withstand a wide variety of environmental conditions, eg extremes of temperature, humidity and salinity of atmosphere. As the normal voltage on board (LV power plants) is 380 v and 440 v, power cables are designated 600/1000 v – 600 v to earth or 1000 v between conductors. Higher voltages (medium voltage power plants for example) require cables rated at 1900/3300 for three-phase, earthed neutral systems and cables rated at 3300/3300 V for three-phase insulated neutral systems.

The type of electrical conductor used to connect components through a power network depends on a number of factors including the conductor's physical size, type of material and electrical properties of the insulation material.

The sample below introduces marine cable coding which was adopted by German manufacturers for LV installations (0.6 –1 kV):

Example: MGCG 3 x 90
M – Marine Cable
Insulation: G – Epr 85 Ethylene – Propylene Rubber
Epr 90 Ethylene – Propylene Rubber
Armour: C – Metal wire Armour (Copper)
D – Metal wire Armour (Galvanised steel)
Sheaths: G – Synthetic Rubber (Polychloroprene)
Y – Thermoplastic Compound

Figures 12.8 and 12.9 illustrate main deck cable tray conditions. The outer insulation has been damaged due to mechanical impact which allows seawater and rain to ingress, which can lead to a short circuit between the conductors.

Figure 12.8 – Damaged outer insulation

Figure 12.9 – Close-up of damaged outer insulation

To prevent cross shortened conductors and emergency power cable replacement in the future, '3M' heat shrink technology can be used to repair cables.

Examples of 3M products which are available:

- 3M HDT-A self-limiting heating cables (heat shrink tubing). This has a hot melt adhesive inner layer and is used for repairing the damaged outer insulation

Figure 12.10 – 3M HDT-A heat shrink tubing

- 3M HDCW heat shrinkable wraparound cable repair sleeve is used for repairing damaged outer insulation.

Heat shrink tubing can also be used when connecting cables and wrapping around cable glands.

Data for ordering is given in Tables 12.5 and 12.6.

Figure 12.11 – 3M HDCW heat shrinkable wraparound sleeve

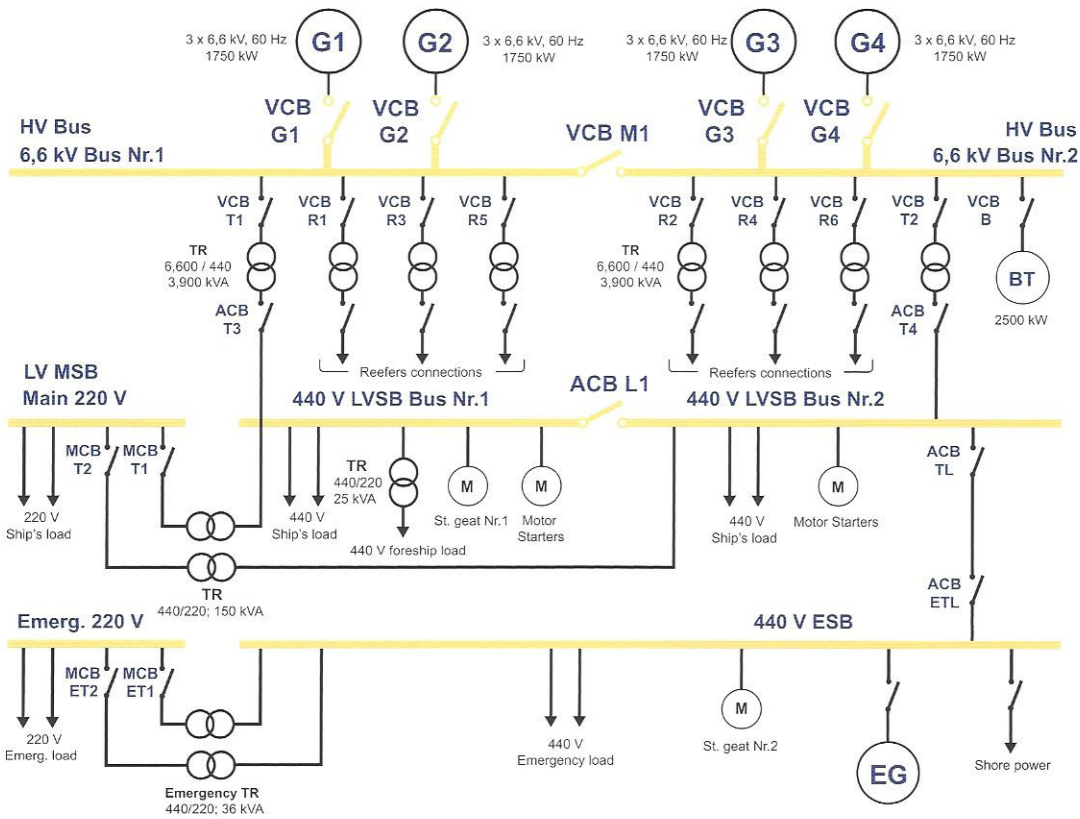
Diameter as Supplied Minimum (mm)	Diameter Recovered Maximum (mm)	Wall Thickness Fully Recovered Total Wall (mm)	Wall Thickness Fully Recovered Meltable Wall (mm)	Standard Pack 1.0 m Length (m)	Standard colour
12.0	3.0	3.2	0.7	100	Black
19.0	6.0	3.3	0.8	100	Black
30.0	8.0	4.8	0.8	40	Black
38.0	12.0	4.8	0.8	30	Black
48.0	15.0	4.8	0.8	15	Black
85.0	26.0	4.8	0.8	8	Black
115.0	28.0	4.8	0.8	5	Black

Table 12.5 – 3M HDT-A heat shrink tubing/hot melted adhesive layer ordering information

Type	L (mm)	C max/min (mm)
HDCW 35/10-250	250	35/10
HDCW 35/10-100	500	35/10
HDCW 35/10-750	750	35/10
HDCW 35/10-1000	1000	35/10
HDCW 35/10-1200	1200	35/10
HDCW 55/15-250	250	55/15
HDCW 55/15-500	500	55/15
HDCW 55/15-750	750	55/15
HDCW 55/15-1000	1000	55/15
HDCW 55/15-1200	1200	55/15
HDCW 80/25-250	250	80/25
HDCW 80/25-500	500	80/25
HDCW 80/25-750	750	80/25
HDCW 80/25-1000	1000	80/25
HDCW 80/25-1200	1200	80/25
HDCW 110/30-250	250	110/30
HDCW 110/30-500	500	110/30
HDCW 110/30-750	750	110/30
HDCW 110/30-1000	1000	110/30
HDCW 110/30-1200	1200	110/30
HDCW 140/40-250	250	140/40
HDCW 140/40-500	500	140/40
HDCW 140/40-750	750	140/40
HDCW 140/40-1000	1000	140/40
HDCW 140/40-1200	1200	140/40

Table 12.6 – 3M HDCW heat shrinkable wraparound cable repair sleeve ordering information

13 High Voltage Systems



G - Generator
LV - Low Voltage
HV - High Voltage
MSB -Main Switchboard

SB - Switchboard
ESB - Emergency Switchboards
BT - Bow Thruster
HV Bus - High Voltage Busbar

VCB - High Voltage Circuit-Breaker
VCB M1 - Bus Tie Breaker
ACB - Air Circuit-Breaker

Figure 13.1 – HV-LV ship's power plant outline

13.1 Introduction

As ships have become larger, power requirements have increased, becoming more sophisticated and introducing higher voltages. As a result, HV distribution is now considered a normal engineering and electrical operational requirement. Modern container ships with a capacity over 3,500 TEU are likely to have HV power plants with 6,600 V.

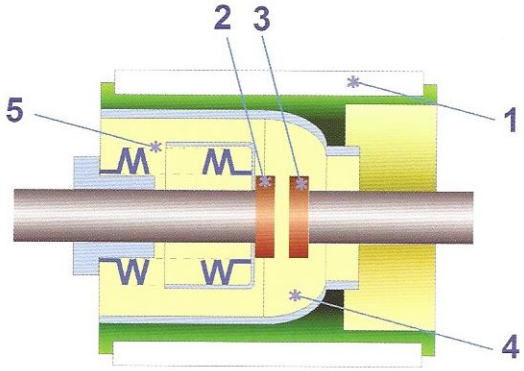
There are two types of HV circuit-breakers used for (1,000 V and higher):

- Vacuum circuit-breakers
- SF6 circuit-breakers.

13.2 Vacuum Circuit-Breakers

When two current-carrying contacts are separated in a vacuum chamber, an arc is created. With AC the current decreases during the wave tending towards zero, reducing, both the vapour and plasma. Once 'zero' is reached, the vapour condenses, building up dielectric strength preventing an arc. This principle is used in these breakers.

Vacuum circuit-breakers (VCBs) were the first type of oil-less circuit-breakers produced. Inside there are vacuum interrupters (Figure 13.1) which are used to make and break load and fault currents. They are permanently sealed in ceramic bottles. These bottles contain movable contacts in a high vacuum.



1. Ceramic bottle 2. Moving contact 3. Fixed contact
4. Metallic screen 5. Seal membrane

Figure 13.2 – HV breaker vacuum interrupter outline

The circuit breaking performance and quality of this design is very high.

Figure 13.3 – M.GERIN HV breaker

The advantages of a vacuum circuit-breaker include:

- Excellent operational safety due to reliable switching on short-circuit faults
- long operational life
- good short time current withstanding ability
- rapid fault clearance
- a voltage suppressor is incorporated
- erosion of contacts is monitored
- the current path requires no maintenance
- any arc is contained.

Figure 13.1 shows a sample of a 6,000 TEU ship's HV–LV power plant equipped with VCBs for:

- HV Bus section breaker M1
- the main generators' breakers G1 to G4
- step down transformers 6.6 kV/440 V T1 and T2 (primary side)
- reefer network transformers 6.6 kV/440 V R1 to R6 (primary side)
- bow thruster breaker (BT).

All the others circuit-breakers used on the 3 × 440 V and 3 × 220 V networks are automatic air circuit breakers (ACBs).

13.3 SF6 Circuit-Breakers

Sulphur hexafluoride (SF6) is a high density inert gas that has a high and rapid rising dielectric strength. SF6 breakers can be used for voltages that range from 3.6 to 760 kV. Advantages of SF6 breakers include:

- There is virtually no danger of ignition
- exceptional arc-extinguishing capabilities
- reduced wear and tear of contacts
- simple and cheap
- low maintenance
- suitable for voltage levels ranging from 3.6 to 760 kV
- no moisture or dust contamination due to sealed construction.

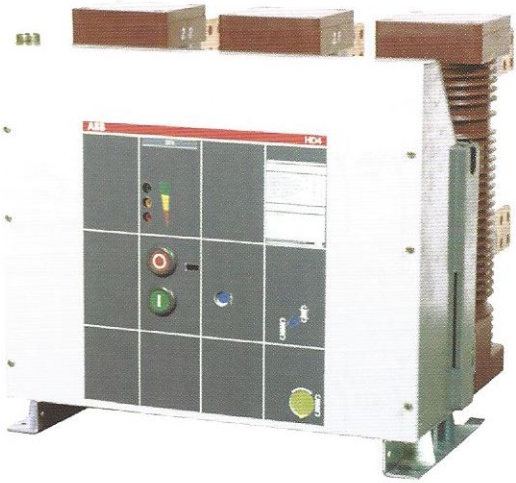
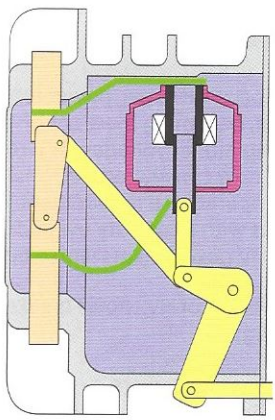


Figure 13.4 – ABB HD-4 (SF6 circuit-breaker)

13.3.1 Breaking Principle

LF circuit-breakers create an arc blowing and quenching effect using the thermal expansion of SF6 gas and a rotating arc.



1)

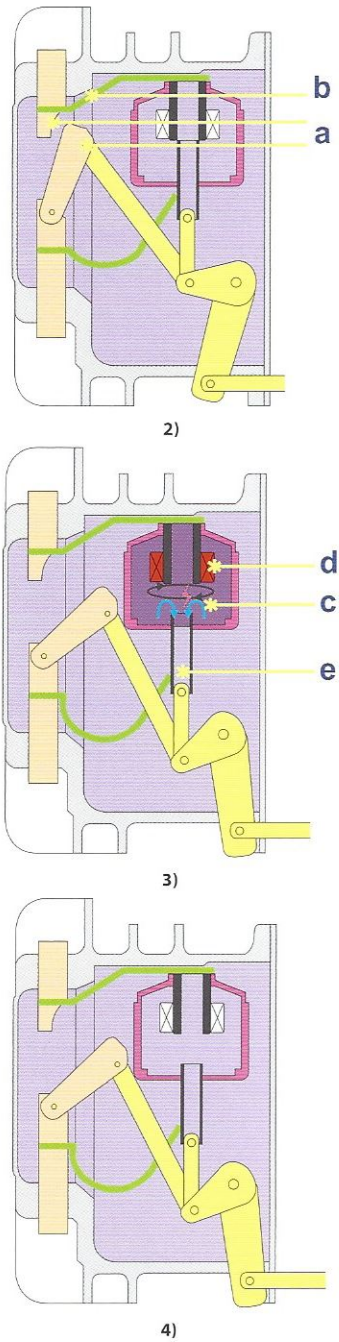


Figure 13.5 – SF6 operating sequence

The sequence of a self-expansion breaking chamber is illustrated in Figure 13.5.

1. The circuit and CB are closed.
2. The main contacts (a) are opened mechanically. The current is shunted into the breaking circuit (b).
3. The arcing contacts separate and an electrical arc is created in the expansion chamber (c). A magnetic field is created by the coil (d) causing the arc to rotate and breaking the current's flow. Overpressure is created by the gas temperature (of the gas blowing the arc inside the arcing contact (e)) increasing, resulting in arc quenching.
4. The circuit and CB are open.

The advantages of this type of CB is a reduction in energy requirements, contact erosion and improved mechanical and electrical longevity.

13.4 Working on HV Systems

The reason for using HV is mainly to reduce the short circuited current, but it also has the advantage of a significant reduction in cable size. During design and selection of equipment for marine use the risk of accident from both HV and LV systems can be reduced by having all switch gears, switchboards and transformers configured so that they cannot come into contact with any live electrical components. All personnel who are required to work on HV systems must have received the appropriate HV training and certification.

13.4.1 Working on HV Equipment

The officers on board with appropriate HV certification are responsible for managing and maintaining the HV plant.

When performing work on HV components, it is normal for the entire switchboard to be isolated and the vacuum breaker racked-out.

All necessary precautions and work permits must be completed before any work commences.

13.4.2 Key Safety Aspects when Working on HV Equipment

1. HV work is non-routine. Before work can commence, a risk assessment must be made, an isolation certificate completed and a work permit validated.
2. The operation must be carefully planned.
3. Equipment and machinery must be secured against unintentional operation.
4. The working area must be clearly marked. Only the work team is allowed to enter. Signs should be posted at the worksite and in the switchboard room to advise of the work being undertaken.
5. Minimum safe distances must be observed.
6. Appropriate PPE must be worn for any HV work.
7. Earth (grounding) cables should be fitted to the plant before being worked on and not removed until the site is clear and ready for connection.
8. Plant and equipment must be tested to ensure there is no voltage present. The high voltage test equipment must be calibrated and in-date.
9. During megger testing the local and switchboard earthing should be removed.
10. Protective shields, covers and earthing equipment should be removed once the work has been completed.
11. Log all work which involves contact with any HV or associated equipment.

14 Step-down Transformers

14.1 Introduction

Transformers, unlike a motor, have no mechanical output (expressed in kW), instead they are characterised by the apparent nominal power kVA that they can supply continuously. However, they are also designed to supply significantly higher power. A three-phase transformer is a combination of three interconnected single-phase transformers with three primary and three secondary windings mounted on a core with three legs (Figure 14.2).

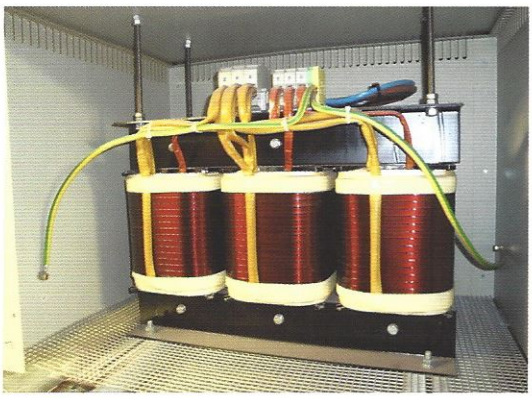


Figure 14.1 – Power transformer

The primary and secondary windings of three single-phase transformers can be connected in the following ways:

- Primary in delta – secondary in delta (D/D)
- primary in delta – secondary in star (D/Y)

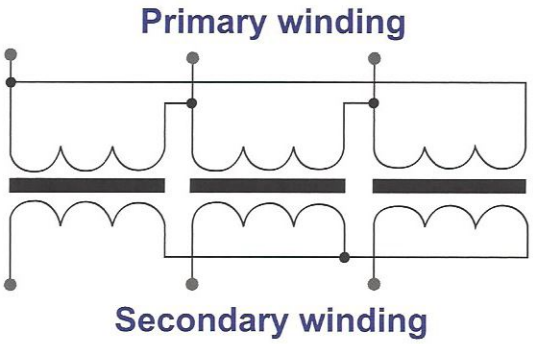


Figure 14.2 – Three-phase delta-star 3 transformer

- primary in star – secondary in star (Y/Y)
- primary in star – secondary in delta (Y/D).

14.2 Low Voltage Power Network

Low Voltage (LV) power plants supply 3 × 380 V/50 Hz, 3 × 440 V/60 Hz, etc, to the power-distribution network. Smaller electrical motors require 3 × 220 V to function. Voltages are reduced from 3 × 380 V to 3 × 220 V. This distributes a reduced voltage to the consumer network.

As there is a lesser voltage in the load side (3 × 220 V) than in the power supply side (3 × 380 V), the current in the load side is greater than the current provided from the source side.

A regular LV power plant has four step-down transformers, shown in Figure 14.3 as T1 to T4. T1

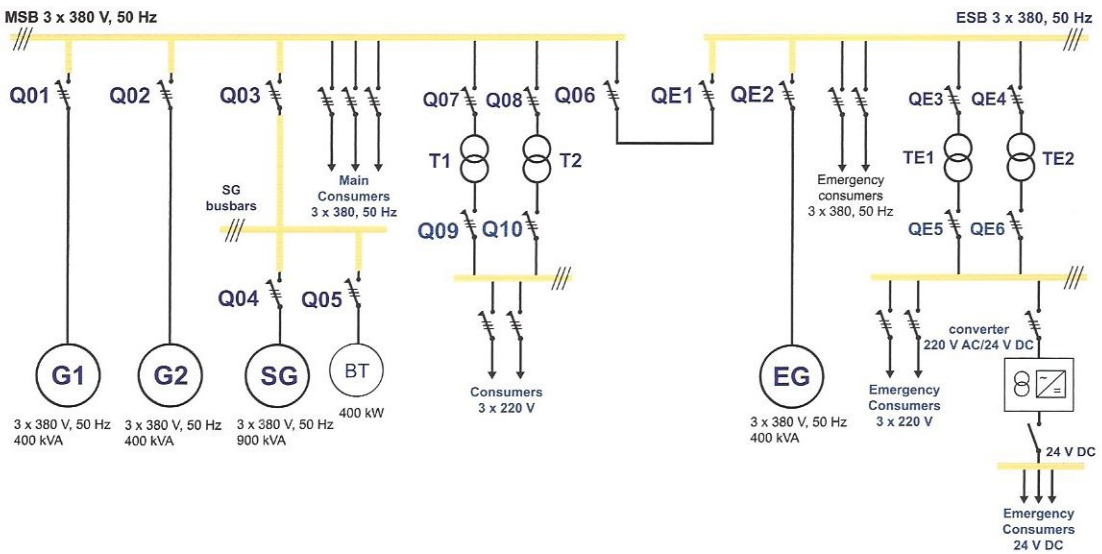


Figure 14.3 – Ship's LV power plant outline

and T2 are located near the main switchboard .T3 and T4 are located in the vicinity of the emergency switchboard. One transformer from each side of the busbar (MSB and ESB) is kept in continuous operation while another is available as a standby unit. It is normal that the primary winding of the transformer is permanently connected to the power supply. The switching of the load is only carried out in the secondary circuit. Therefore, the standby transformer can be kept separate from the power network until required.

14.3 Transformer Parallel Operation

All transformers are hardwired to the power network during the construction process. The power plant manufacturer will have followed the requirements for parallel operation, ie:

- The supply and load voltages are equal for both transformers
- short circuit voltages for both transformers are equal
- the load carried by both transformers are equal
- the type of connection to both primary and secondary windings are equal.

Figure 14.4 illustrates features of 3 x 380 V/3 x 220 V distribution, where T1 and T2 are step-down transformers, Q7 and Q8 are automatic circuit-breakers for primary windings (supply) and Q9 and Q10 are automatic circuit-breakers for secondary windings (load).

If T1 is in operation and T2 is intended to be paralleled with T1, and T1 is scheduled to be put on standby, the following sequence for Q7 – Q10 circuit-breakers should be followed:

For bringing -T2 in parallel:

- Primary winding circuit-breaker Q8 must be closed first
- secondary winding circuit-breaker Q10 must be closed last, connecting -T2 under the load.

For switching off -T1:

- Secondary winding circuit-breaker Q9 must disconnect the load from T1 first
- primary winding circuit-breaker Q7 must then disconnect T1 from the supply voltage.

A similar sequence should be exercised for emergency switchboard transformers.

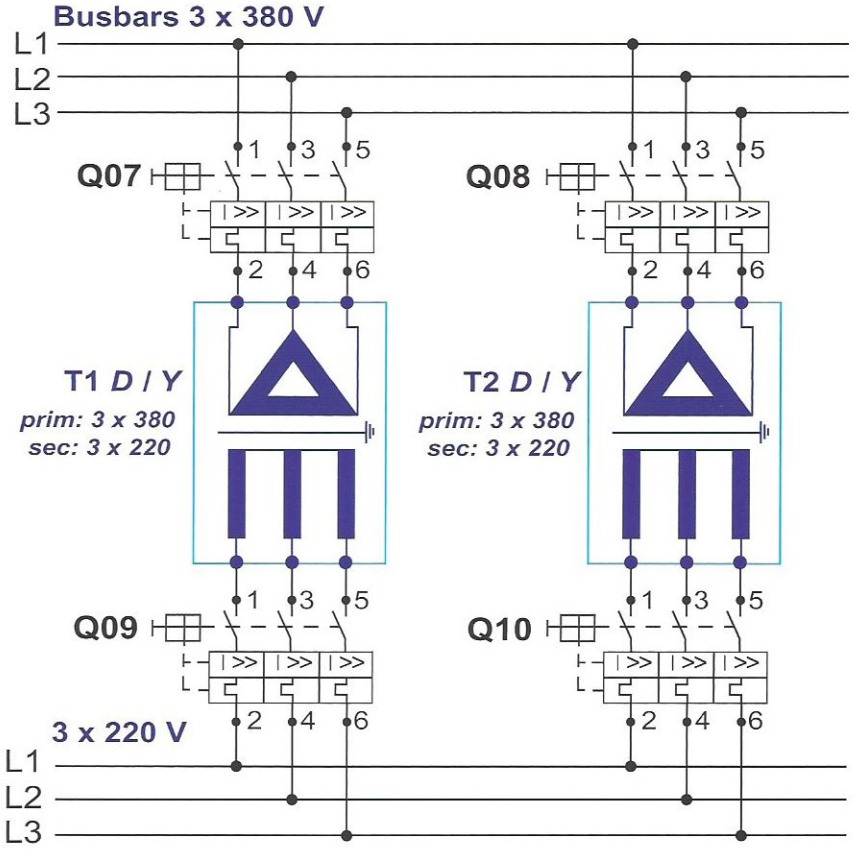


Figure 14.4 – Step-down transformers' network outline

15 Generator Neutral Systems

15.1 Power System Networks

In power supply systems, an earthing system defines the electrical potential of the conductors relative to the Earth's (ground's) conductive surface. International standard IEC 60364 distinguishes three families of earthing arrangements, using the two-letter codes TN, TT and IT.

The first letter indicates the connection between the earth and power-supply equipment (generator or transformer):

T – Direct connection of a point with earth (from the word 'terre' meaning earth)
I – no point is connected with the earth (isolation), except perhaps via a high impedance.

The second letter indicates the connection between the earth and electrical device being supplied:

T – Direct connection with the earth, independent of any other earth connection in the supply system
N – connection to earth via the supply network.

In a TN-earthing system, one of the points in the generator or transformer is connected with earth, usually the star point in a three-phase system. The body of the electrical device is connected via this connection at the transformer.

The conductor that connects the exposed metal of the consumer is called a protective earth (PE). The conductor that connects to the star point in a three-phase system is called neutral (N).

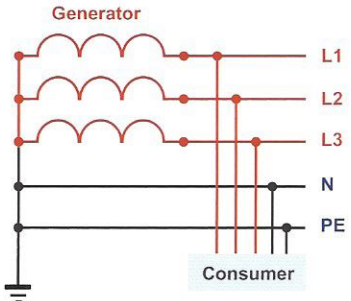
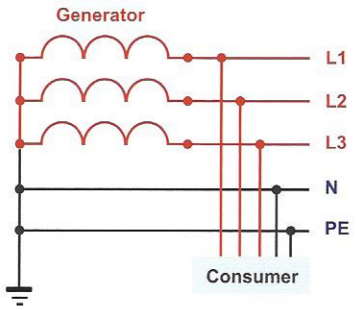


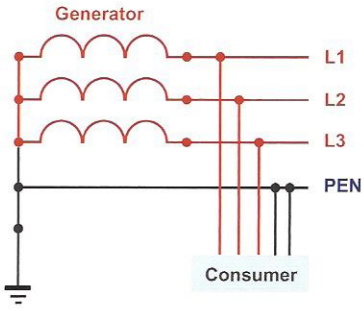
Figure 15.1 – TN-network

To avoid an electric shock caused by an insulation fault (a short circuit to the ground), the PE connection maintains the exposed conductive surface at the same electrical potential as the earth. In an insulation fault, a very high current flow triggers an overcurrent protection device (fuse, circuit-breaker) that disconnects the power supply.

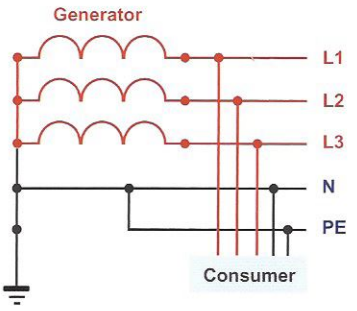
Three variants of TN systems are shown in Figure 15.2:



a) TN-S



b) TN-C



c) TN-C-S

Figure 15.2 – TN systems outline

TN-S PE and N are separate conductors that are only connected near the power source, Figure 15.2.a.

TN-C A combined PEN conductor fulfills the functions of both a PE and an N conductor, from the power source to the consumer, Figure 15.2b.

TN-C-S Part of the system which uses a combined PEN conductor. It is split into separate PE and N lines, Figure 15.2c.

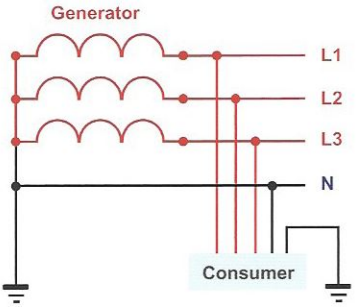


Figure 15.3 – TT-network

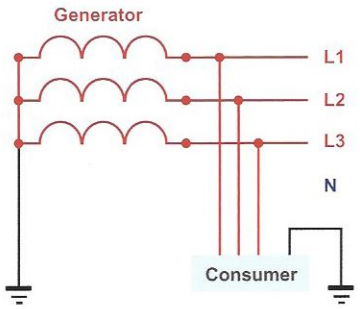


Figure 15.4 – IT-network

In a **TT-earthing system**, Figure 15.3, the consumer's protective earth connection is provided by a local connection to earth which is independent of any earth connection at the generator.

In an **IT-network**, the distribution system, Figure 15.4, does not have a connection to earth (or only has a high impedance connection). In such systems, an insulation monitoring device is used to monitor the impedance.

15.2 Ship Power Systems

An insulated power system is totally isolated from the ship's hull, referred to as 'isolated from earth' and is illustrated in Figure 15.5.

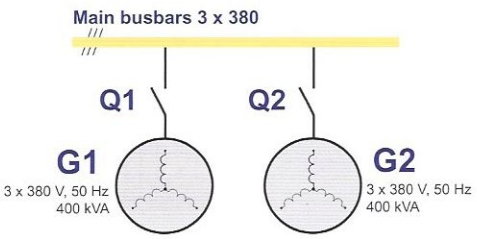


Figure 15.5 – LV insulated power system outline

It is common for power plants on ships to be insulated from earth. However, earthed marine power systems, where the generator's neutral point is connected to the earth, can also be found, Figure 15.6.

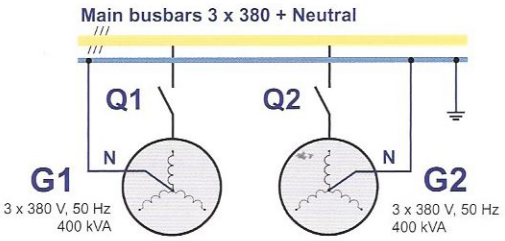


Figure 15.6 – LV earthed neutral power system outline

Ships' LV power systems are usually directly earthed to neutral, as illustrated in Figure 15.6. The neutral in HV systems is connected to the ship's hull via a Neutral Earthing Resistor, also known as a Neutral Point Resistor (NPR), as illustrated in Figure 15.7. In this system an earth fault causes the current to flow through the neutral connection conductor via the NPR, limiting the current.

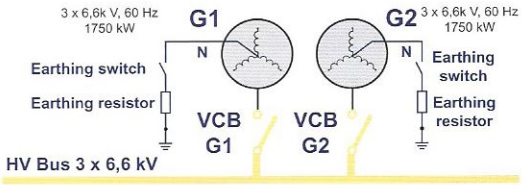


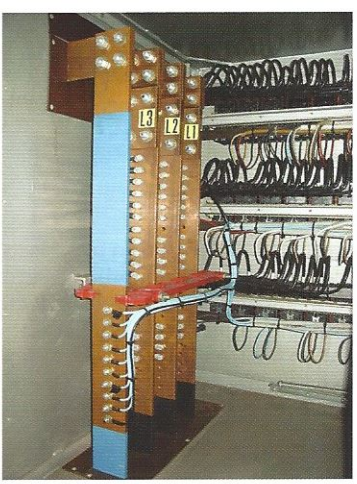
Figure 15.7 – HV system neutral earthing circuits' outline

NPRs are made from metal plates and are rated during construction in order to meet the requirements of the system protection scheme. These requirements include considering the maximum accepted fault current, the earth potential levels and minimising the damage which could be caused under fault conditions.

15.3 LV Earthed Neutral System 220 V Network Features

The power distribution network example, shown in Figure 15.8, was taken from an earthed neutral system.

a)



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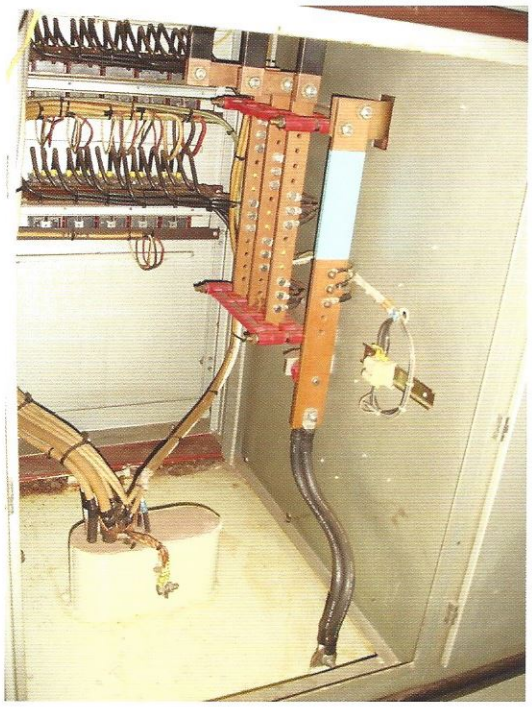


c)

Figure 15.8 – Ship's LV earthed neutral power system. Overview at MSB busbars

As previously mentioned in Chapter 14, three-phase power step-down transformers are not used on board for 3 × 220 V distribution if the generator's neutral is connected to the side of the switchboard busbar, where it is earthed. Figure 15.8 a) and b) show that the main busbars (3 × 380, L1, L2 and L3) are accompanied by a fourth busbar that is earthed, Figure 15.8c. This busbar, colour-coded light blue, is called Neutral. The outline of the LV power distribution incorporating the earthed neutral conductor is illustrated in Figure 15 .9.

If an earth fault occurred on the live line of an earthed distribution system, the equivalent would be a short circuit fault across the generator's neutral through the ship's hull. The resulting earth fault current would immediately cause the line protective device, miniature circuit-breaker and motor starter protector, etc, to trip the faulty circuit. The failed equipment would be immediately isolated from the supply.

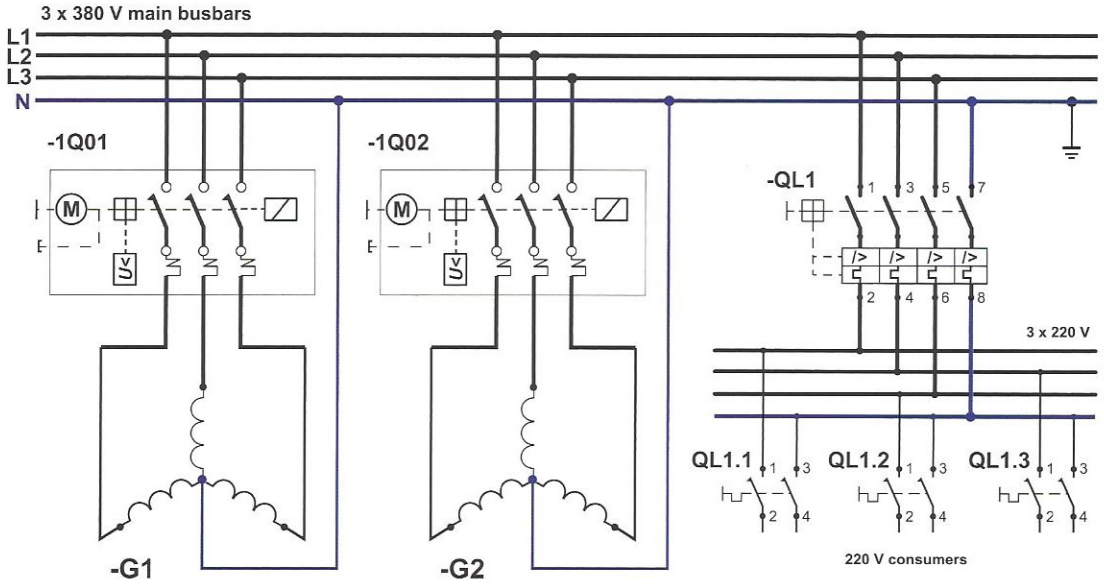


Figure 15.9 – Ship's 220 V network with earthed neutral bus

Insulation Resistance Monitoring on an AC Network

16

16 Insulation Resistance Monitoring on an AC Network

16.1 IR Basics

Harsh marine installation environments, especially those with extremes of temperature and/or sea humidity, will result in electrical insulation deterioration. An earth fault can occur if a life conductors' insulation is either partially or completely broken, causing a short circuit. As a result, the safety of personnel and power reliability will be affected.

What is insulation resistance testing? This involves applying DC voltage across a dielectric, measuring the amount of leakage current flowing through that dielectric, and then calculating (using Ohm's Law) a resistance. The resistance measurement is in megohms. This resistance measurement is used to evaluate insulation integrity.

Insulation resistance is temperature sensitive. When temperature increases, insulation resistance decreases, and vice versa. A common rule is that insulation resistance changes by a factor of two for each 10°C change. So, to compare new readings with previous ones, it is necessary to correct the readings to a base temperature. For example, if the measurement was 100 megohms with an insulation temperature of 30°C. A corrected measurement at 20°C would be 200 megohms (100 megohms times two).

Insulation resistance is measured with the megohmeter (Figure 16.1). The megohmmeter's output is much higher than that of a multimeter (voltages of 250, 500, 1000 are used for onboard testing). Higher voltages are used to stress an insulation to a greater degree and obtain more accurate results. The megohmmeter has a relatively high internal resistance that makes the instrument less hazardous for personnel to use in spite of the applied higher voltages.

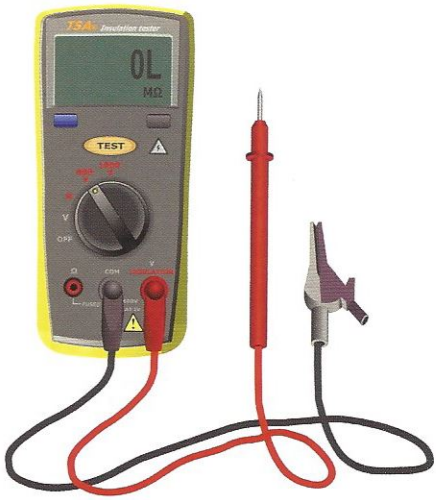


Figure 16.1 – Megohmmeter

16.2 IR Monitoring Onboard

Marine power plant installations are required to maintain an uninterruptible power supply to essential consumers, even if there are single- or multi-earth fault occurrences. AC network insulation resistance monitoring is part of the ship electricians' and engineers' daily routine.

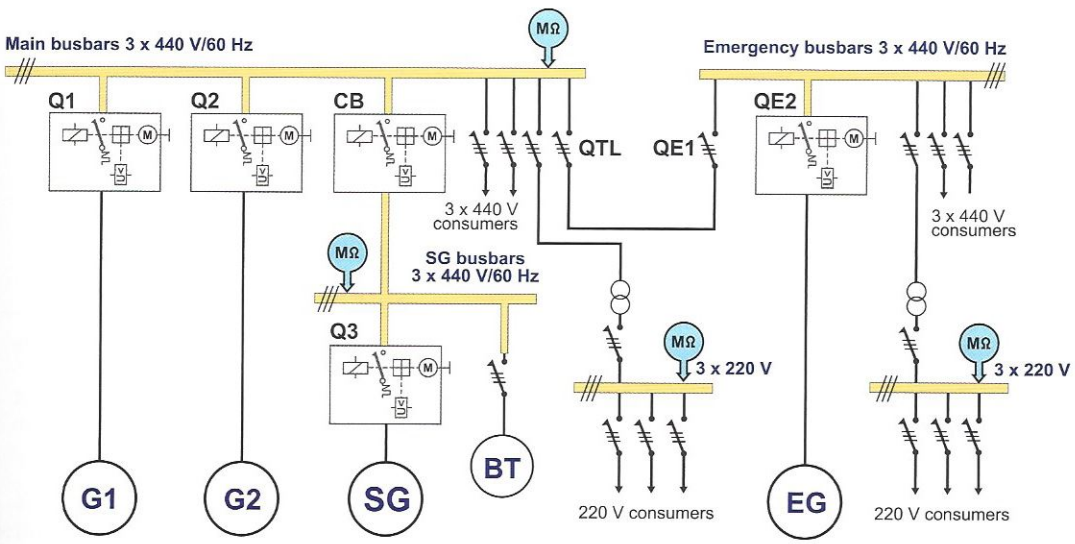


Figure 16.2 – SAM Electronics marine power network insulation monitoring outline

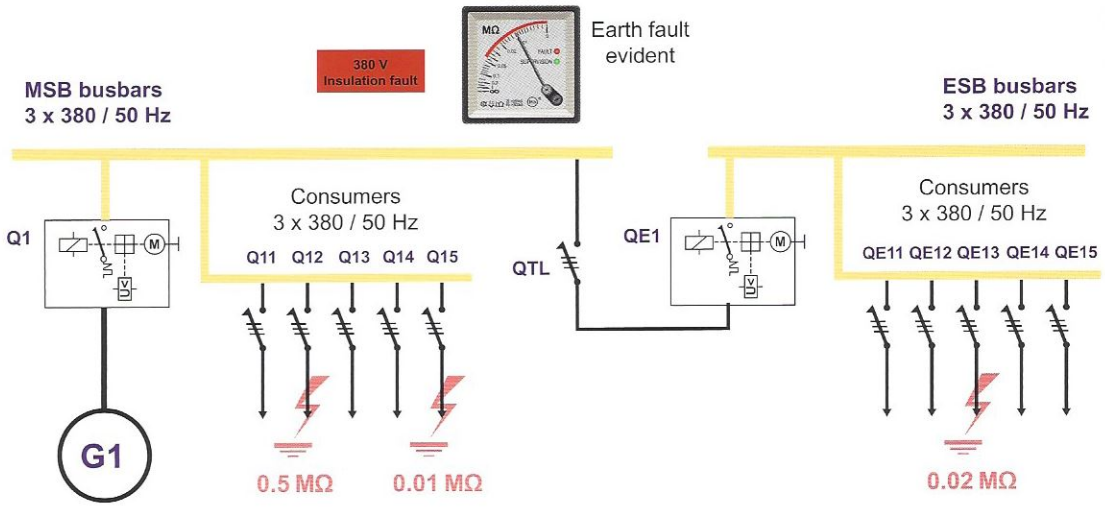


Figure 16.3 – Earth fault monitoring

As illustrated in Figure 16.2, Marine Power Network by SAM Electronics is continuously monitored for insulation resistance by four MΩ – instruments situated at:

- The 3 × 440 power network (main busbars and emergency busbars)
- the shaft generator (SG) busbars
- the 3 × 220 power network (two separate instruments for main and emergency panels).

An arrangement of insulation monitoring instruments at the side of the 3 × 440 V distribution allows insulation control of both the main and emergency networks with a single instrument when main busbars are fed from G1 and/or G2. To locate the earth fault, it will be necessary to clarify if the short circuit is associated with the main or emergency network. This can be done by dividing the power plant in half by disconnecting the transfer line breaker QTL (or QE1).

Figure 16.2 shows a troubleshooting example, an insulation meter connected from the side of the main switchboard gives an earth fault alarm and shows a value of 0.01 MΩ. There are three simultaneous low values showing grounded consumers that are traced as follows:

- Two shown on the side of the main consumer network (0.5 MΩ and 0.01 MΩ)
- one on the side of the emergency consumer network (0.02 MΩ).

By isolating the entire 440 V consumers' network from the side of main busbars through opening all circuit breakers Q11 to Q15 on the MSB, an earth fault of 0,02 MΩ remains. However, if we would additionally isolate Transfer Line circuit breaker QTL (or QE1) meantime holding on entire main network isolated, insulation monitor alarm extinguishes (monitor will indicate an *infinity* value). Then, by isolating QE11 through QE15, an another earth fault would be traced.

It is important that every low-state insulation incident should be investigated as soon as possible to avoid any further deterioration of the electrical integrity of the ship.

Figure 16.4 shows the insulation monitor DEIF (Danish Electro Instrument Factory) DIM-Q intended for continuous monitoring of three-phase AC marine power networks where the neutral of the generator is not earthed. The instrument shows a normal operating condition, ie no fault (green LED).

The instrument requires an AC auxiliary voltage to operate.

An example of insulation monitoring for a marine power plant manufactured by SAM Electronics using DEIF DIM-Q is illustrated in Figure 16.4. Test buttons –S3 and –S4 are intended for earth fault simulation and connecting terminals P to test resistors -R1 and -R2.

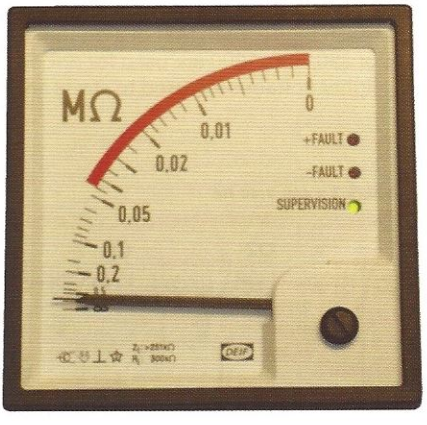


Figure 16.4 – DEIF insulation monitoring instrument

The insulation is monitored between the complete AC network, irrespective of the number of wires and a safety cable. The measurement is carried out by applying a DC voltage between a point on both the safety cable and the AC network. A condition for monitoring the complete network is that the remaining parts are galvanically connected. This is normally achieved via the windings of the generator, supply transformer or the connected loads.

The DIM-Q is equipped with three LED indicators, one green and two red. Only the green indicator marked 'Supervision' is lit when the unit is connected to an auxiliary supply and no isolation error is detected. If the DIM-Q detects a change in the isolation measurement, the Supervision LED flashes at a fast rate.

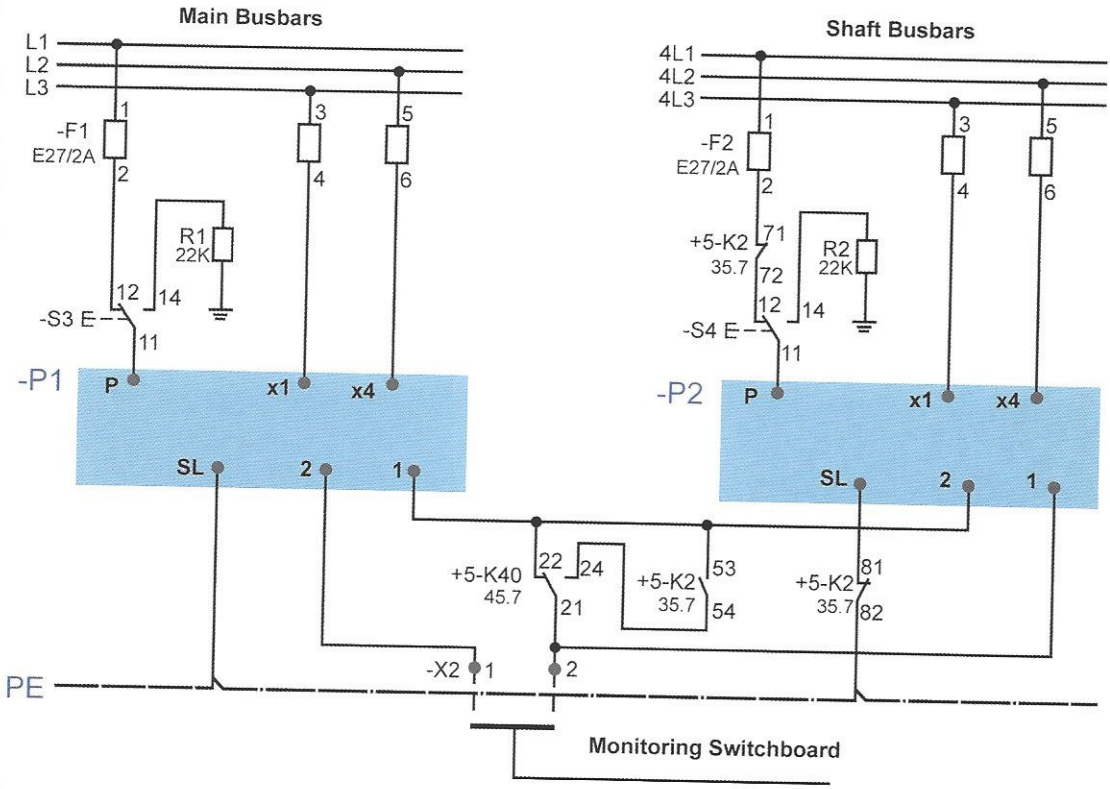


Figure 16.5 – DEIF instrument wiring for SAM Electronics ship's power plant

Synchronous Brushless Alternators Excitation Systems

17

17 Synchronous Brushless Alternators Excitation Systems

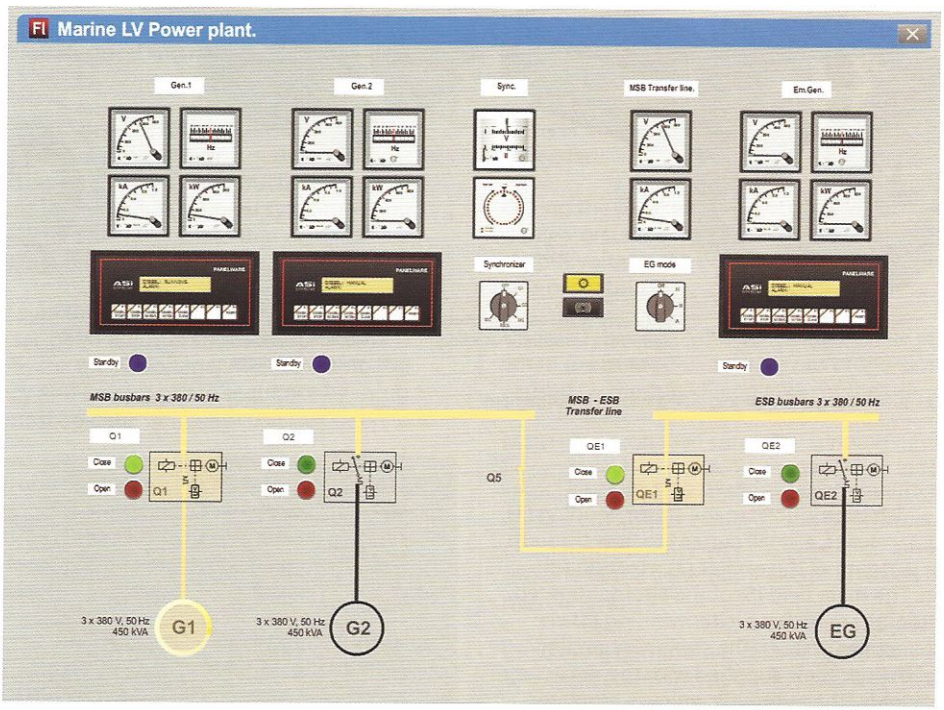


Figure 17.1 – Marine LV Power Plant simulator based on SAM Electronics ASI Power Management

Synchronous brushless alternators are installed on most ships today as the main or standby units for marine power installations.

17.1 Synchronous Brushless Generator Basics

A synchronous brushless generator, as shown in Figure 17.2, is a compact unit consisting of one inner-pole main machine (1 and 2) with salient or non-salient pole rotor, one external-pole exciter (3 and 4) with a rotating rectifier (5) and one exciter device with electronic voltage regulator (6).

17.1.1 Stator Core and Winding

The stator core is built from laminated steel with windings housed in slots around the inner periphery of the cylindrical core. The stator coils are interconnected, in the end-winding regions, to form three separate phase windings which are normally in a star configuration with a Neutral point. The four stator ends are arranged in the terminal's box on top of the generator, where they are connected to the stator terminals. The main outgoing cables connected to these terminals conduct the generator's electric power to its circuit-breaker at the main switchboard.

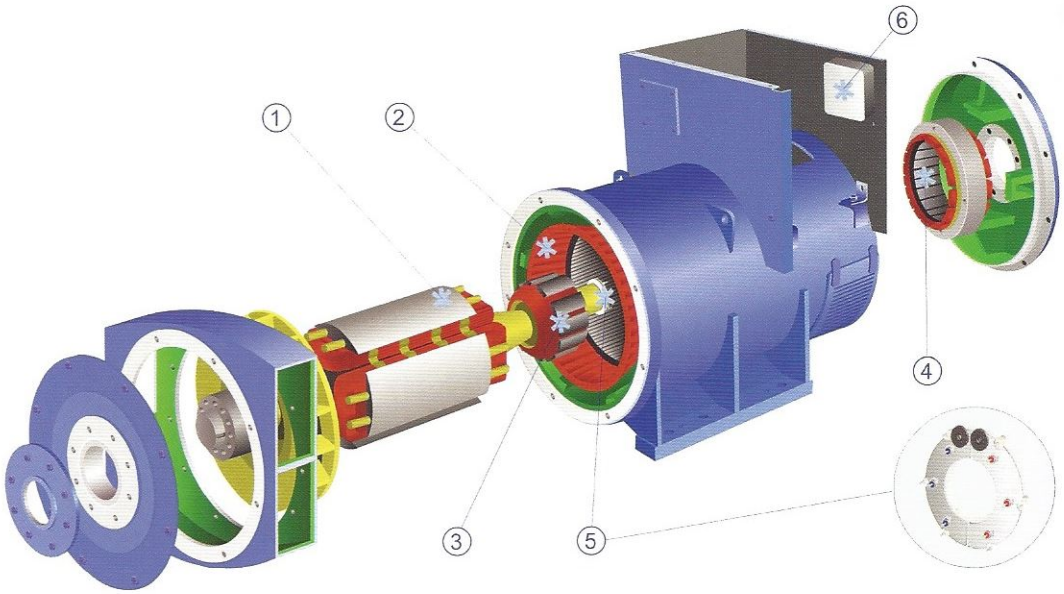
High voltage stator windings are made by applying the most recent developments in engineering and materials. Modern alternators use several different insulation systems depending on the voltage rating. This insulation features a high percentage of mica. Conductors are insulated with varnish and a double layer of glass fibre of a high dielectric strength. The insulation is baked under pressure to completely eliminate any air and obtain a homogenous layer. The winding end turns are insulated with polymerised mica tape, simultaneously providing dielectric strength and elasticity. The final layer protects the insulation against detrimental atmospheric and chemical influences. To protect the stator winding against thermal overload, PTC sensors or Pt 100 sensors are often used.

17.1.2 Rotor Core and Winding

The rotor of a main AC generator provides the field excitation from its electromagnetic poles. Figure 17.2 is an illustration of a salient pole type of rotor.

17.1.3 Generator Excitation

The stator supplies the exciter via an excitation unit, the voltage regulator controls the field current necessary to obtain constant alternator voltage. An example of a brushless generator excitation system is given in Figure 17.3.



1. Rotor core with rotor winding
2. Stator core with stator winding
3. Exciter rotor
4. Exciter stator
5. Rotating rectifier
6. Voltage regulator

Figure 17.2 – Brushless generator excitation system arrangement

The excitation principle is based on a residual voltage, which is produced in the stator winding (1), Figure 17.3, causing a small current to flow through the stator winding of the exciter (3), creating self-excitation. The main field (5) of the alternator is fed by the three-phase rotary exciter winding (4) via a rotating rectifier unit (7). The stationary exciter field (3) of the exciter is supplied with the necessary direct current by the automatic voltage regulator, AVR (8). Self-excitation is secured by the residual magnetism of the rotary exciter field (5). The input power supply for the AVR (8) is provided by the auxiliary field (2), which is working as a transformer in the armature winding (1). The AVR senses the generator output voltage and compares it with an internal reference voltage set by a potentiometer (9). Adjustments are made to its output (3) which is supplying excitation to the rotary exciter field (5) to maintain a constant generator output voltage. The reactive droop compensation circuit (10, 11) can be used for parallel operation as a voltage booster to compensate line droop. Overvoltage suppression (6) gives the rotating rectifier's diodes (7) protection against overvoltage spikes generated in the exciter field.

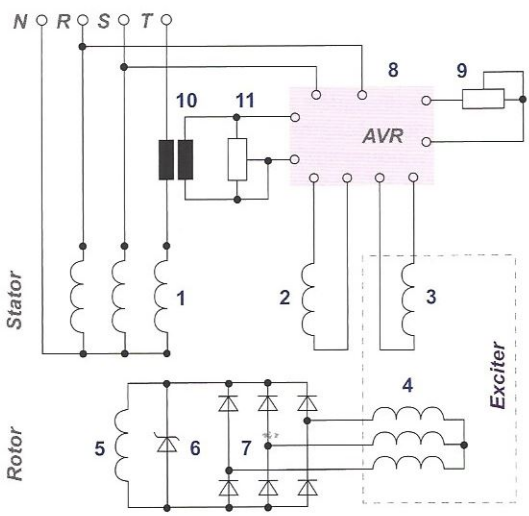


Figure 17.3 – Generator excitation system

The output voltage can be adjusted in a range of +/- 5% of the nominal voltage by an external potentiometer or one incorporated within the AVR. An external potentiometer or a motor potentiometer can be connected to remotely adjust the voltage.

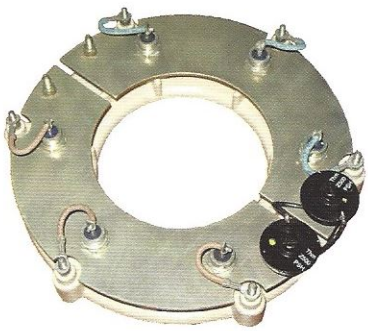


Figure 17.4 – Rotating rectifier unit

17.1.4 Parallel Operation Load Sharing

During manoeuvring and cargo operations in port, generators must run in parallel to share the total ship's load which often exceeds the capacity of a single generator. Changeover procedures that take power from the working generator to the standby unit also require parallel operation.

All brushless generators are designed for parallel operation. The generators can be synchronised either by manual synchronisation, quick synchronisation or automatically.

The following pre-requisites must be met for the synchronisation process:

- Almost identical frequency of the two voltage systems (frequency deviation is less or equal to 0.2 Hz)
- almost identical terminal voltage of the generator and mains network (admissible difference is less than 6%)
- identical phase sequence of the two voltage systems.

Incorrect synchronisation causes extremely high electrical and mechanical loads.

Classification Societies require that at least two different ways of synchronising generators must be provided when a vessel is constructed. Figure 17.5 represents the main switchboard synchronisation panel built by SAM Electronics that enables synchronisation as follows.

Manual synchronisation

Use the set-point adjuster to set the generator voltage to the mains voltage. After selecting the frequency and correct phase sequence by using a synchronoscope, the generator can be put on line.

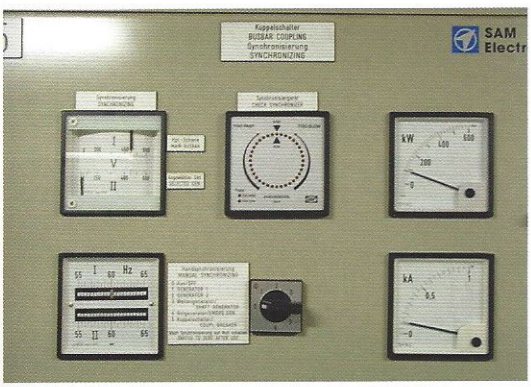


Figure 17.5 – SAM Electronics power plant - synchronisation panel

Automatic (quick) synchronisation

Use any synchronisation device to automatically adjust the system to the smallest voltage, frequency and phase differences possible. The device should also take the switching delay times in the zero crossover range of the difference in voltage into account for switching on.

For the parallel operation of several generators, current and power outputs as well as reactive power distribution variations must be within the range of applicable regulations, eg GL requires the current deviation to be kept within 10%. A pre-requisite for this type of operation is for generator drives, in particular their speed governors, to be designed correspondingly, providing the same P-droop range (speed drop between idle and full load operation). Alternatively, this can be achieved by ensuring that the non-inductive load distribution is proportional to the power output, made possible by installing an automatic non-inductive load distribution system.

Setting the speed controllers of the primary or prime movers, ie the source of mechanical power, to share the active power proportionally ensures a steady parallel operation. The primary mover speed should be adjusted equally to avoid any problems with imbalance. The reactive load may cause trouble if the power is not shared proportionally.

To provide reactive load sharing, the alternator output must show a droop characteristic that increases with the applied load. The error signal produced across the current transformer in Figure 17.3 (10) burden resistor (11) must be applied to the AVR sensing voltage to cause an appropriate droop characteristic.

The voltage droop of the regulator is usually adjusted to approximately 10%. This adjustment allows a mains-voltage deviation of +/- 2.5%, where the reactive current limits of the alternator are not exceeded.

During the parallel operation of brushless generators, a reactive load sharing at constant output voltage can be achieved by cross current compensation.

Unequal sharing of the generators' active power, when the output kW value is not proportional, is caused by the speed regulation of the prime movers.

Managing high load surges by running generators in parallel when a difference in reactive load sharing takes place will cause large circulating currents to appear between the generators. These circulating currents may become large enough to trip one of the generators' circuit-breakers due to an overcurrent.

Circulating currents are caused by an excitation of system components (including AVR). To avoid a generator being severely damaged, the following procedure should be carried out to trace the cause of the fault as soon as possible:

- Check that all drives have the same percentage value for speed drop between idle and full speed while in single operation
- use the set-point adjuster to adjust the idle voltages of all generators. The idle voltage must be approximately 5% higher than the voltage under load
- set the nominal load at the nominal power factor on the generators in single operation. If possible, check whether an almost identical voltage drop can be observed for all generators
- replace the AVR.

In the past, reactive power was distributed between generators using carbon brushes and slip-rings to connect the rotor winding to the AVR. Running generators in parallel took advantage of a compensation line that connected their excitation windings in parallel.

In Figure 17.6, wiring the compensation line is achieved by connecting it via the auxiliary contacts of the generator's circuit-breakers (or auxiliary relay contacts). If there was a surge or drop of kVAR it would be shared equally between the generators.

Despite this power regulation being carried out by modern AVRs, brushless generator manufacturers still produce this 'classic style' of compensation circuit.

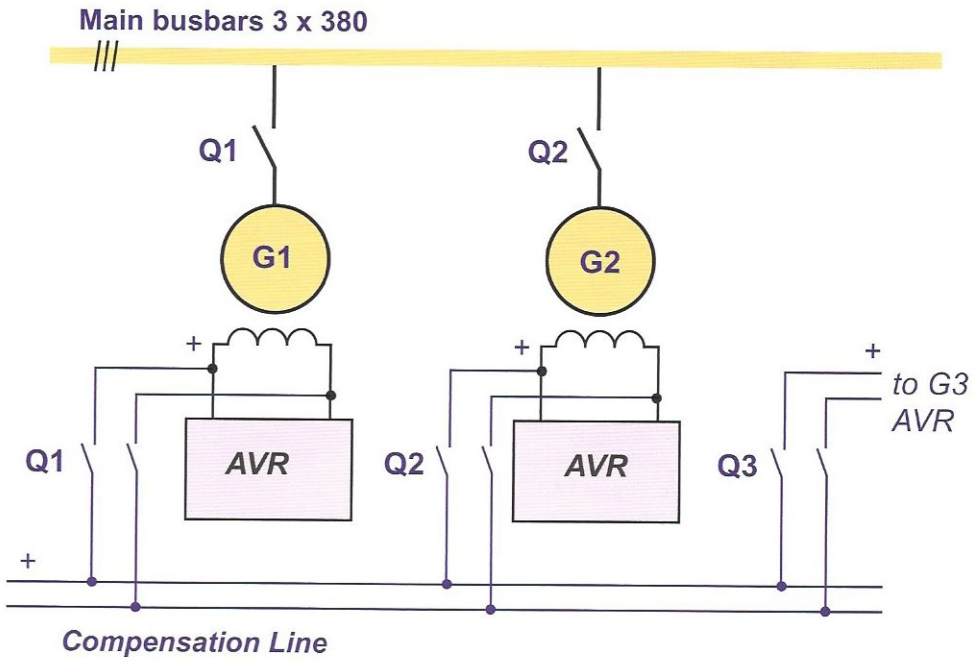


Figure 17.6 – Compensation line wiring principle

Cause	Effect During Single Operation	Main Effect During Parallel Operation
Preset generator's voltage is higher	Generator's output voltage increases	Generator provides more reactive power
Generator's statics/droop is lower	No effect	
Preset generator's voltage value is lower	Generator's output voltage decreases	Generator provides less reactive power
Generator's static/droop is higher	No effect	
Preset speed value of primary mover is higher	Generator's net frequency increases	Generator provides more non-inductive power
Preset speed value of primary mover is lower	Generator's net frequency decreases	Generator provides less non-inductive power

Table 17.1 – Generator effect during operation under load

17.1.5 Generators in Operation

The following table illustrates the different effects that may be expected from a generator running under load, either singularly or in parallel with another unit.

17.1.6 Automatic Voltage Regulator (AVR)

When load surge is experienced, eg when a ship's cargo lifting equipment picks up a heavy cargo, the generator voltage dips as a result. Similarly, load shedding will result in a generator overvoltage. In other words, on board there is no such thing as a constant load. Therefore, a continuously fluctuating generator voltage must be regulated.

The AVR regulates the generator's output voltage by regulating the voltage of the main field (rotor's winding). This particular device ensures that the voltage is maintained within the required range and rapidly corrects any voltage deviations caused by load dips and shedding. In addition to regulating the generator voltage, the AVR circuitry includes protective features to ensure safe and reliable control of the generator.

Modern AVRs consist of high quality electronic components. The components are usually cast with epoxies (Figure 17.7), which protect against high temperatures, moisture and vibration.

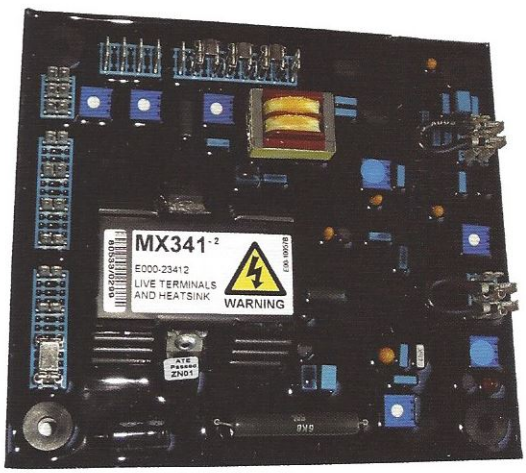


Figure 17.7 – Stamford AVR

A replacement AVR, if required, must be installed in accordance with the manufacturer's installation requirements.

17.1.7 Troubleshooting Tips

If the generator produces either no voltage or fluctuating voltages, try to locate the problem. Check all connectors and cables in the terminal box and the exciter components for secure connections.

While tracing a problem with an AVR and/or excitation system, the following checks can be carried out (Table 17.2).

17.1.8 Generator Insulation Testing

It is advisable that insulation resistance is measured when the generator is at ambient temperature. A generator that has an insulation value of below 1 M Ohm should not be in service. All generators have a heater incorporated to maintain the insulation characteristics required for electrical components. This activates when the generator comes to a stand still.

Be aware of remnant voltage. Do not touch the conductors before or after the test is carried out. Always disconnect the AVR and all devices that are connected with the earth before carrying out a megger test.

17.2 Understanding Power Factor

Distribution systems are typically made up of a combination of resistive, inductive and capacitive loads.

True power (P)
Power used by a purely resistive circuit produces useful work and is known as true power. True power in a resistive circuit is equal to **P = U I** (voltage times current).

Resistive loads
Resistive loads are loads in a solely resistive circuit, caused by devices such as heating elements. In a resistive circuit, the current and voltage rise and fall *in phase.*

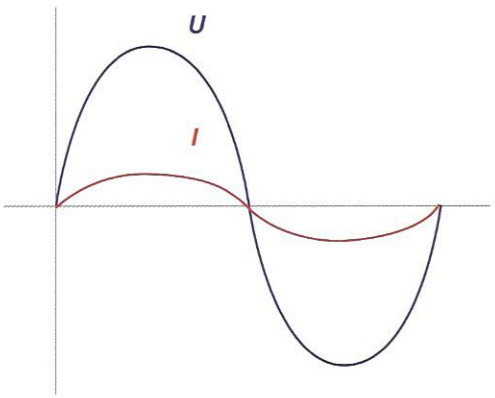


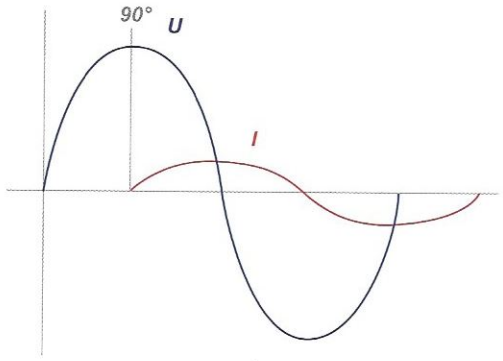
Figure 17.8 – Resistive load

Inductive loads
In a purely inductive circuit, ie a circuit where the change of current induces an electromagnetic force, eg motors and transformers, the current lags behind the voltage by 90° and is out of phase.

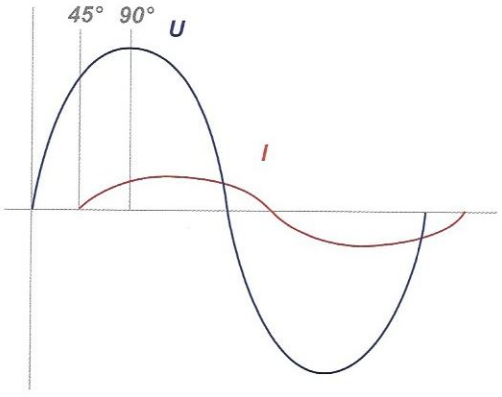
However, in reality inductive circuits contain resistance, the amount of resistance and inductance means that an AC current will lag somewhere between a purely resistive circuit (0°) and a purely inductive circuit (90°).

Fault Description	Action Suggested
No voltage build-up when starting set	Follow separate excitation or residual voltage tests
Loss of voltage when set running	First stop and re-start set If there is no voltage or the voltage collapses after a short time, follow the 'separate excitation test procedure'
Generator voltage high followed by collapse	Check sensing leads to AVR. Check isolating transformer secondary output - refer to the separate excitation test procedure
Voltage unstable, either on no-load or with load	Check speed. If correct, check voltage stability setting. Refer to the load testing procedure from the manufacturer
Voltage low on load	Check speed. If correct, check voltage stability setting. Refer to the load testing procedure from the manufacturer
Phase voltages unbalanced	Check stator winding and cables to the main circuit-breaker
Excessive voltage/speed dip on load switching	Check governor response and P-droop adjustment for the governor
Sluggish recovery on load switching	Check governor response and P-droop adjustment for the governor

Table 17.2 – Troubleshooting chart



a)

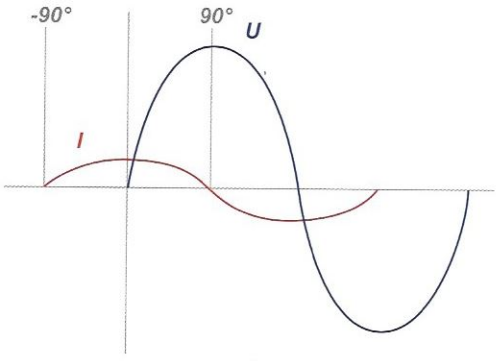


b)

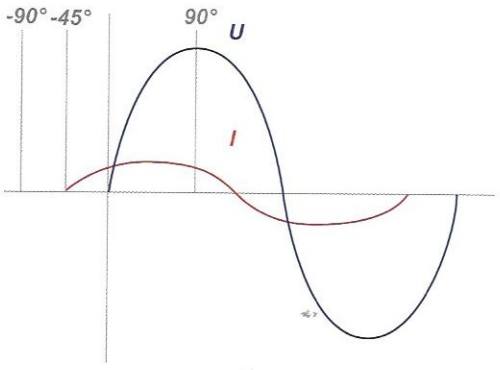
Figure 17.9 – Inductive loads

Capacitive loads

In a purely capacitive circuit, current will lead voltage by 90°. Capacitive circuits, however, have some amount of resistance. Depending on the amount, an AC current will lead voltage somewhere between a purely resistive circuit (0°) and a purely capacitive circuit (90°).



a)



b)

Figure 17.10 – Capacitive loads

Reactive loads

Reactive loads are circuits with inductive or capacitive components which can be found in most distribution systems. The amount of resistance and reactance depends on the loads that are connected.

Reactance

Similar to resistance, which opposes current flow in a resistive circuit, reactance opposes current flow in a reactive circuit.

It should be noted that while frequency has no effect on resistance it does affect reactance. Increasing frequency increases inductive reactance and decreases capacitive reactance.

Energy in reactive circuits

In reactive circuits, energy does not produce work, it is used to charge capacitors or produce the magnetic field around the coil of an inductor. During the time an AC current is rising to its peak value, energy is stored in an inductor in the form of a magnetic field, or as an electrical charge in the plates of a capacitor. When the magnetic field collapses, energy is released, ie when the magnetic field collapses or when the capacitor is discharged.

Reactive power (Q)

Reactive power in an AC circuit represents the energy that is alternately stored and returned to the system by capacitors or inductors measured in volt-amps reactive (VAR). While not producing useful work, it is required to provide sufficient true power to run electrical processes.

Apparent power (S)

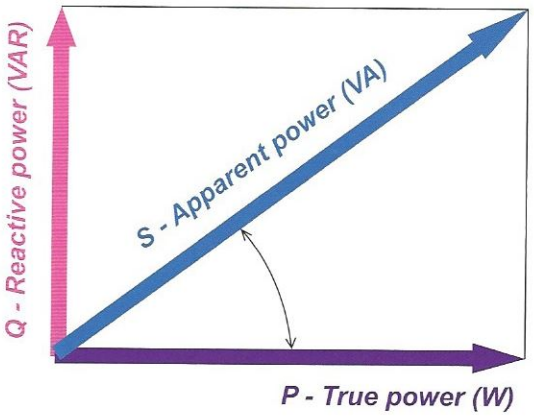


Figure 17.11 – Apparent power

Apparent power is the vector sum of true power, representing the load that includes both the reactive power and true power. Although it has been established that reactive power does not produce useful work, when a motor rotates, work is produced and inductive loads, eg motors, have a degree of resistance. The unit of measurement for apparent power is volt amps (VA).

Power factor

Power factor (PF) is the ratio of true power (P) to apparent power (S), or the amount of power consumed in respect of the amount returned to the source. Power factor is equal to Cos φ in Figure 17.13 and is the phase difference between current and voltage.

Apparent power and true power are equal in entirely resistive circuits, where the power that is supplied is consumed or is dissipated as heat. In which case the angle φ is 0° and the power factor is equal to 1 (unity power factor). In reactive circuits, apparent power and reactive power are equal and the power supplied is returned to the system. The angle φ is 90° and the power factor is 0. However, in real AC circuits, both resistance and reactance exists.

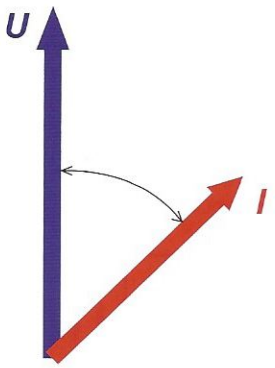


Figure 17.12 – Power factor in real circuits

Review:

- Power dissipated by a load is referred to as true power. True power is symbolised by the letter P and is measured in watts (W)
- power merely absorbed and returned in load due to its reactive properties is referred to as reactive power. Reactive power is symbolised by the letter Q and is measured in the unit of Volt-Amps-Reactive (VAR)
- total power in an AC circuit, both dissipated and absorbed/returned is referred to as apparent power. Apparent power is symbolised by the letter S and is measured in the unit of Volt-Amps (VA).

Leading and lagging power factor

As current leads voltage in a capacitive circuit, power factor is considered as leading if there is more capacitive reactance than inductive reactance. Power factor is considered lagging if there is more inductive reactance than capacitive reactance, because current lags voltage in a inductive circuit. The power factor is in unity when there is no reactive power or when inductive reactance and capacitive reactance are equal.

Power factor problems

An increase in the reactive power of a power plant causes a decrease in the power factor. This means that the power distribution system is operating less efficiently because all current is not performing work.

Power factor correction capacitors, shown in Figure 17.13a, can be added to a power plant to improve the power factor (fixed capacitor banks). Individual capacitors can also be used for motor control centers and other control panels, Figure 17.13b.

a) b)

Figure 17.13 a) and b) – Capacitors

Power factor correction

Power factor is the ratio between KW and KVA and measures the usefulness of the current applied to the load. A poor power factor may be due to a significant reactive component of the current. A lagging power factor is common due to an inductive load, eg induction motors, chokes, lighting ballasts and transformers. A lagging power factor can be corrected by the addition of power factor correction capacitors. Poor power factor caused by a high level of harmonic currents of variable speed drives, rectifiers and discharge lighting cannot be corrected except by using expensive filter circuits.

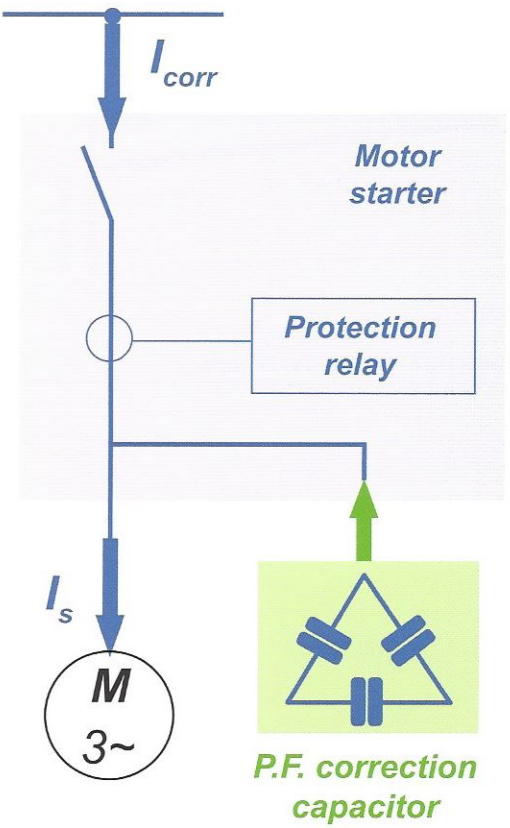


Figure 17.14 – P.F. correction outline

Power factor correction is applied to circuits which include three-phase induction motors (Figure 17.14) as a way of reducing the inductive component of

the current, reducing the losses in the supply. There should be no effect on the operation of the motor itself. Power factor correction can be achieved by adding capacitors in parallel with motor circuits and can be applied at the starter, switchboard or distribution panel.

The power factor of an asynchronous three-phase motor is inductive and is typically within the range of 0.8 to 0.9. A low power factor indicates wasted electrical energy. It further reduces the distribution capacity of the power system by increasing the current flow and causing voltage drops.

Figure 17.15a represents an uncorrected motor current, where IS, IP, and IQ are the apparent, actual and inductive currents, respectively.

For correcting the inductive current IQ of the motor, a capacitor producing capacitive current IQC is used.

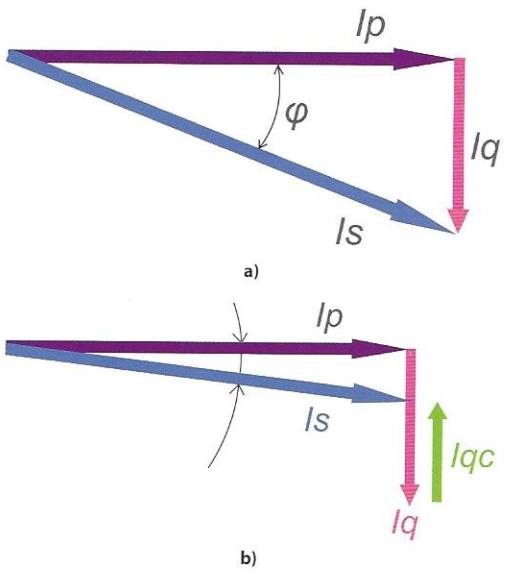


Figure 17.15 – P.F. correction principle

Figure 17.15b represents the way that PF correction capacitors act. The capacitive current IQC of the capacitor compensates for the inductive current of the motor IQ. As a result, the corrected motor current is smaller than the rated current of the motor. The motor protection settings must be based on the corrected motor current, otherwise the motor will be under-protected.

The current measured by the motor protection relay, Figure 17.16, is the corrected motor current, the relay settings must be adjusted to take account of the degree of correction. This is irrespective of whether the correction capacitor is connected before the relay measuring point or a centralised correction capacitor (connected directly to the busbars) is used, the relay will measure pure motor current. In these cases, the correction does not affect the relay settings.

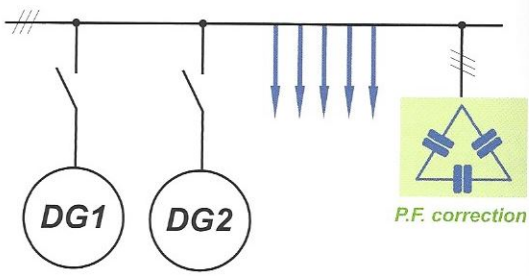


Figure 17.16 – Motor protection relay

Capacitors which are connected to and controlled by each starter are known as Static Power Factor correctors, while capacitors connected at a distribution board and controlled independently from the individual starters are known as Bulk Correctors.

Process Monitoring. Sensors in Practice

18

18 Process Monitoring. Sensors in Practice

18.1 Introduction

Reliable instruments and sensors have always been an integral part of process control and are essential in any automated system. Development in digital electronics has led to the concept of centralised recording and display stations with associated data processing, computing and control systems. Controlling applications with accurate measuring, variable converting and remote signal transmission has involved a close relationship between measuring, processing and control systems. Almost any physical property of a material that changes in response to some excitation can be used to produce a sensor. Sensors that are widely used for marine automation include those which are: resistive, inductive and capacitive.

18.2 Resistance Temperature Detectors

Resistance Temperature Detectors (RTDs) are wire wound or thin film devices that measure temperature by using the physical principle of positive temperature coefficient (PTC) and the electrical resistance of metals. The hotter they become, the higher the value of their electrical resistance.

The metals which are best suited for RTD applications are: platinum, copper or nickel. They all have linear resistance-to-temperature characteristics and an ability to withstand repeated temperature cycles.

Figure 18.1 – Pt 100 RTD

RTDs made of platinum are usually known as Pt 100 (Figure 18.1). They are the most popular type of RTD, with linear characteristics which are suitable for a wide range of monitoring temperatures.

The lead wires used to connect an RTD to a readout appliance can contribute to a measurement error, particularly when long lengths of lead are involved, as often happens in remote temperature measurement locations. Calculations are straightforward, there are three or four wire designs to help minimise or limit such errors (as shown in Figure 18.2b, c).

Depending on the type of Pt 100 RTD connection, there can be different faults.

2-wire circuit

The resistance of the cable to Pt 100 (highlighted in blue) must be considered before operation as it may alter the measurements. Fluctuations in temperature contribute to a variation in the line resistance causing a discrepancy in the final measurements.

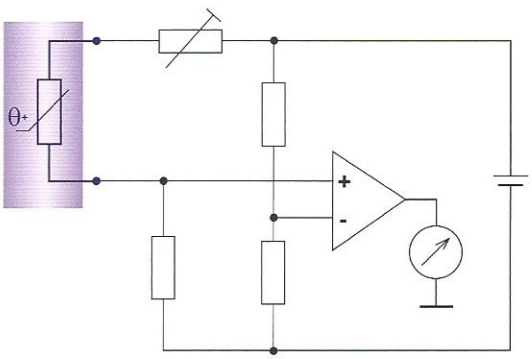


Figure 18.2a – Pt 100 RTD's 2-wire connection outline

3-wire circuit

In this type of connection, the third line is used to compensate for temperature fluctuations. The compensation circuitry results in a measuring error of typically 0.1%.

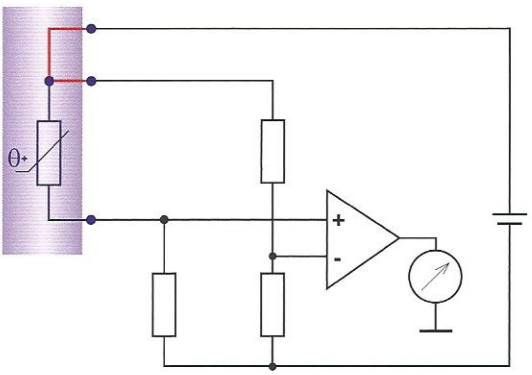


Figure 18.2b – Pt 100 RTD's 3-wire connection outline

4-wire circuit

A 4-wire connection does not produce any additional measuring errors and is considered as

perfect. Therefore, the additional line compensation is not required.

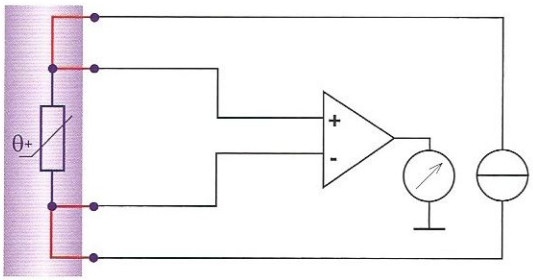


Figure 18.2c – Pt 100 RTD's 4-wire connection outline

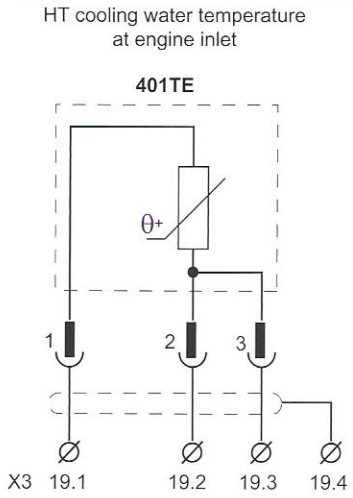


Figure 18.3 – HT system Pt 100's wiring details Wärtsilä L38 engine

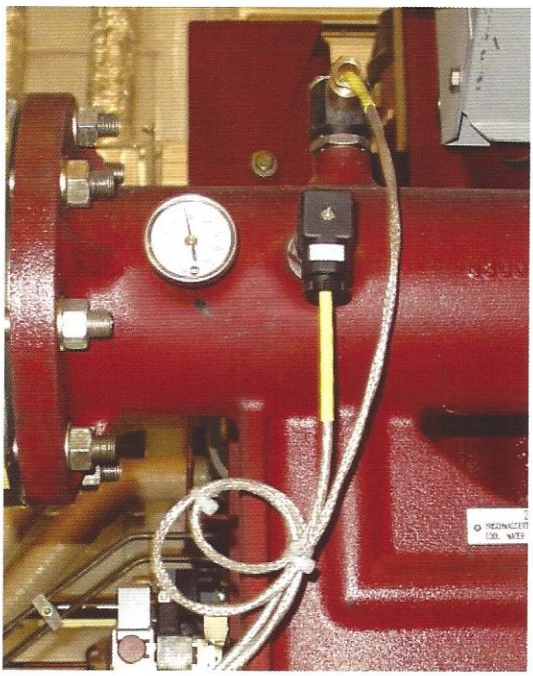


Figure 18.4 – Pt 100 probe HT System MaK M43 engine

The operating ranges of Pt 100s are from -200 to +850°C, the most common range is -100 to +600°C for standard sensors with no additional protective measures or special housing.

Figure 18.5(a) and (b) illustrate typical Pt 100 sensors for measuring liquid temperature. Figure 18.5(c) illustrates a typical Pt 100 sensor for measuring bearing temperatures.

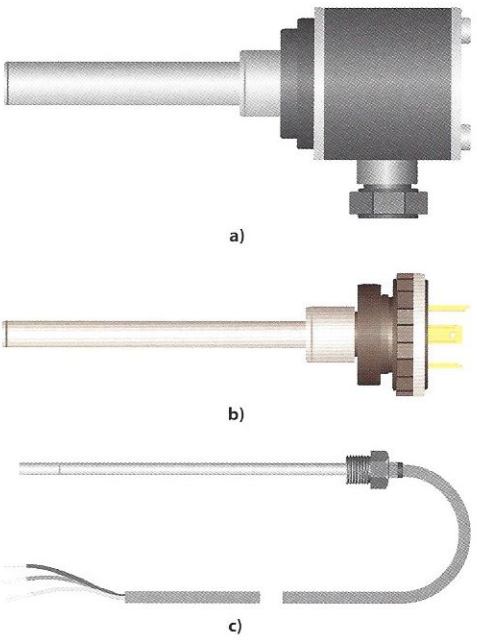


Figure 18.5 – Pt 100 temperature probes' overview

18.2.1 Pt 100 Resistance Data Table and Characteristic

The sensor is made of a platinum thread. The standard Pt 100 RTD resistance at ice point is 100 Ω. The sensor's characteristics may be expressed as:

$$R = 100\ (Ohm) + T(°C) \times K$$

R: the sensor resistance measured in Ω
T: the sensor temperature measured in °C
K: the sensor constant for the typical measuring range 0 - 150°C is 0.385 Ohm/°C.

°C	0	10	20	30	40	50	60	70
Ω	100	103.9	107.8	111.7	115.5	119.4	123.2	127.1

°C	80	90	100	110	120	130	140	150
Ω	130.9	134.7	138.5	142.3	146.1	149.8	153.6	157.3

Table 18.1 – Pt 100 resistance data table

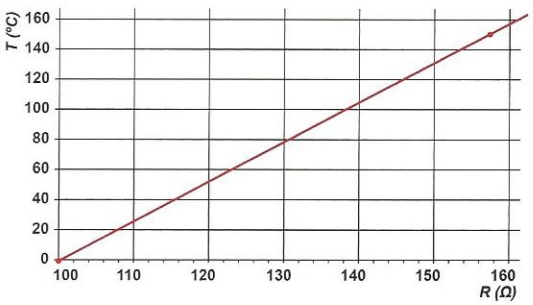


Figure 18.6 – Pt 100 characteristic

18.2.2 Pt 100 Compensation Circuit Resistance

Temperature in °C	*Pt 100/1-2 Terminals in Ω*	*Pt 100/2-3 Terminals in Ω*
0	*100*	*0...5*
50	*119.4*	*0...5*
100	*138.5*	*0...5*
150	*157.3*	*0...5*

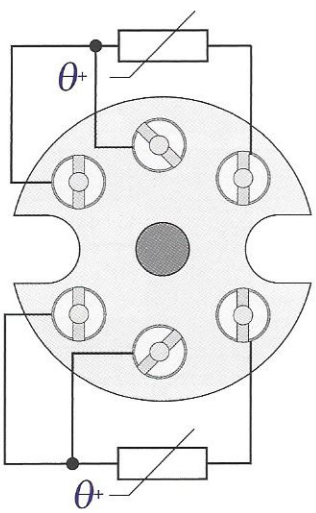
Tag Nr.	Tag Name	Description	Sensor	Channel Type	Termination Board	Source/ Destination
10118	*201TE.1*	*LO temp at inlet*	*Pt 100*	*AIN*	*TB01B-2C* *TB01B-2A* *TB01B-2B*	*CC3-10* *CC3-8* *CC3-9*
10119	*401TE*	*HT water temp at inlet*	*Pt 100*	*AIN*	*TB01B-3A* *TB01B-3B* *TB01B-3C*	*CC3-14* *CC3-15* *CC3-16*

Table 18.2 – Pt 100 probes' data sheet for Wärtsilä L38 engines

18.2.3 Double Pt 100 Sensors

Double Pt 100 probes provide the opportunity to obtain two independent signals which are measured from a single measuring point. They are often employed for security reasons. If one part of the double sensor breaks, the other part can be reconnected from the side of the Pt 100 junction box to ensure that the system will continue working safely. The connective features of a double Pt 100 probe is illustrated in Figure 18.7.

a)



b)

Figure 18.7 – Pt 100 double element (3-wire) overview and connections

Up to four Pt 100 sensors can be incorporated in one sensor casing.

18.2.4 Pt 100 for Temperature Compensation

DIN rail mounted 4-wire Pt 100s for cold junction compensation (CJC) are used to provide each measuring point with compensation circuitry (Figure 18.8).

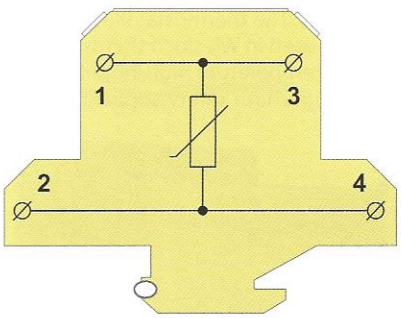
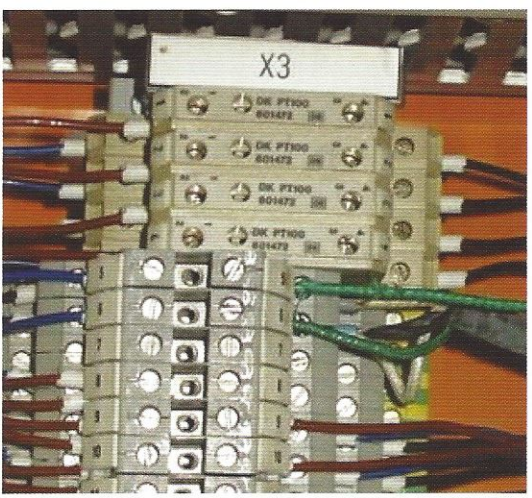
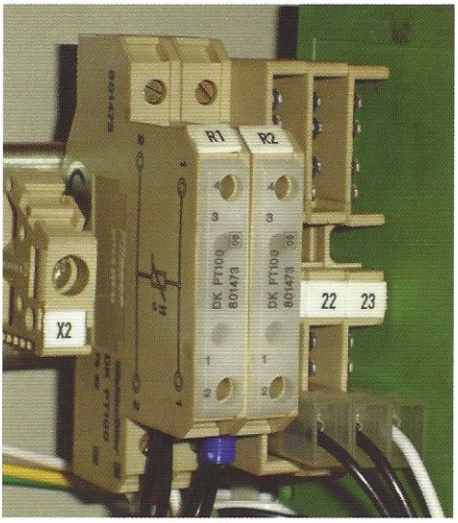


Figure 18.8 – DIN rail mounted compensation unit

Examples of Pt 100 sensors, which are used for temperature compensation of main engines' monitoring circuits, are illustrated in Figure 18.9.



a)



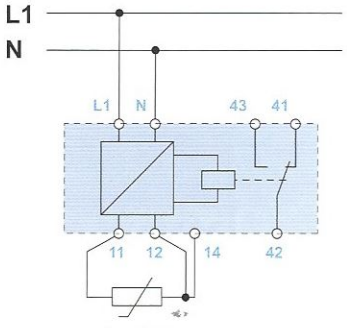
b)

Figure 18.9 – a) Wärtsilä L38 engine MTB temperature compensation Pt 100 probes
b) MaK M43 engine control board temperature compensation Pt 100 probes

18.2.5 Solid State Thermostats (Electronic Temperature Relay)

Solid state thermostats control the temperature by using an on/off action and are commonly used where temperature parameters are controlled by safety circuits. The thermostat illustrated in Figure 18.10 is used in Wiesloch thermal oil boilers as 'thermal oil temperature high/high' and 'flue gas temperature high/high' safety appliances.

a)



b)

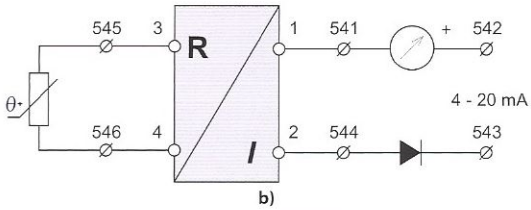
Figure 18.10 – a) JUMO TE-1WO solid state thermostat
b) Thermostat's wiring example

The miniature relay at the controller's output switches the load in accordance with the temperature at the probe (Pt 100 sensor). The probe value is selected using an analogue scale with a knob on the front of the controller. Probes that can be connected are either 2-wire or 3-wire Pt 100 sensors. A 3-wire connection is illustrated in Figure 18.10b. If a 2-wire Pt 100 probe is used, a reference temperature is required at the probe point to accurately adjust for the operating conditions. This can be achieved with an inbuilt zero-correction trimmer.

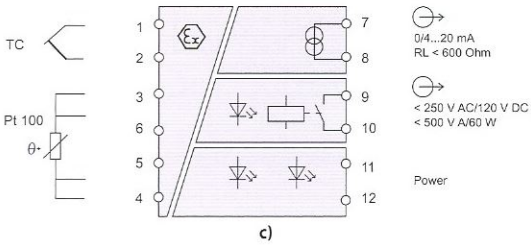
18.2.6 Resistance to Current Converters

Lead errors can be minimised by using either a temperature transmitter which is mounted close to a Pt 100 or a Resistance to Current (R/I) converter (Figure 18.10). Both appliances convert the resistance measurement into an analogue current signal that can be transmitted to a data acquisition or PLC-based controller.

a)



b)



c)

Figure 18.11 – a) TURCK IM34-12Ex-Ri temperature measuring amplifier/converter
b) R/I transmitter external connections
c) R/I converter external connections

18.2.7 Troubleshooting Pt 100s

To verify if a Pt 100 sensor is working and that the output value is accurate with respect to the measuring temperature, the following tests should be carried out:

- Test the Pt 100 sensor with a digital multimeter across the PLC input terminals
- verify with the DMM that the sensor compensation wiring is connected
- verify that the sensor resistance responds to temperature (Figure 18.12). Refer to the characteristics given in Figure 18.6 to compare data
- ensure that neither the sensor nor cable has a short circuit to the ground (check the cable conductor's continuity with the earthed terminal)
- using a process calibrator an Ohm-signal can be simulated instead of the Pt 100 output signal, to find out if the control unit has malfunctioned.

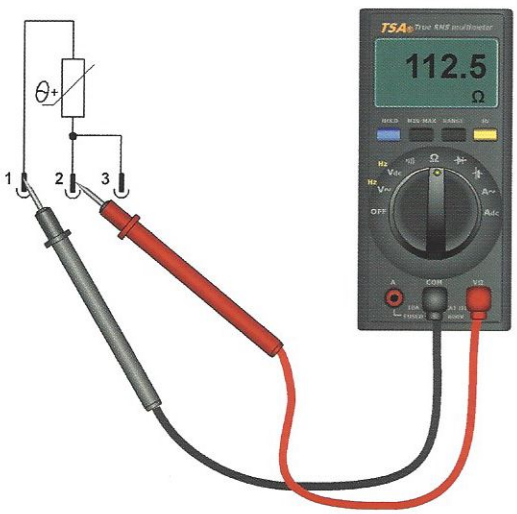


Figure 18.12 – Measuring 3-wire Pt 100 resistance across sensor's terminals

Some deficiencies which are common to Pt 100 sensors are incorporated in Table 18.3.

Problem	*Possible Cause*
Temperature reading too low	• *Short circuit* • *Pt 100 dirty* • *Pt 100 damp* • *3-wire system wired incorrectly*
Temperature jumping	• *Bad connection in loop*
Temperature reading too high	• *Open circuit due to cable break* • *Loose connector* • *Connectors eroded or dirty*

Table 18.3 – Common problems related to Pt 100 sensors' circuits

18.3 Thermocouples

When two different metals are joined and are subjected to different temperatures, a constant voltage is generated. This effect is known as the thermo junction effect or Seebeck Effect. The amount of voltage that is generated will depend on the types of metal used and the temperature. This thermoelectric force is used for measurements by utilising the connected ends of the wire as a measuring point and bringing the open ends of the wires to a constant or measurable temperature (reference junction).

Seebeck Effect is the thermoelectric effect where the voltage potential increases with temperature (thermocouples) in a junction of different metals.

The thermoelectric force directly reflects the difference in temperature between a measuring point and reference point. Therefore, temperature control with thermocouples provides a relative temperature indication, not an absolute indication.

To avoid or at least minimise mistakes, the cables from the thermocouple (measuring point) to the reference junction must have the same thermo-electric characteristics as the thermocouple itself. Those cables are called equalising conductors (Figure 18.13). They are colour coded for an easy match with the respective thermocouple.

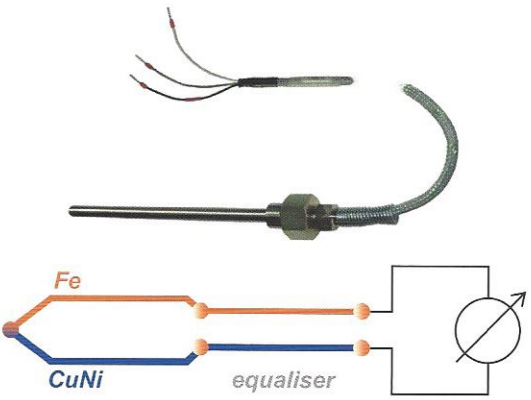


Figure 18.13 – Thermocouple wiring principle

A colour code for extension grade wires is given in Table 18.4.

Many types of thermocouples are available in respect to *DIN IEC 584-1* (Table 18.5). However, the most common types for installations on ships are either Type J or K, because their characteristics are nearly linear within the entire range of working temperatures.

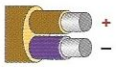
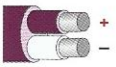
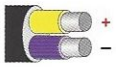
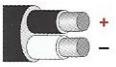
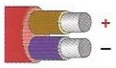
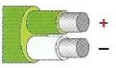
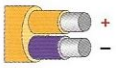
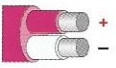
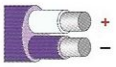
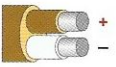
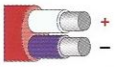
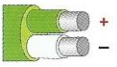
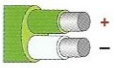
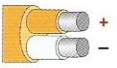
TC Code	Conductors +/–	Insulation Colour Codes Extension and Compensation Leads		
		Standard BS 1843: 1952	New Standard IEC 584-3: 89, mod. BS 4937. Part 30.93	
E	Nickel Chromium/Constantan			EX
J	Iron/Constantan			JX
K	Nickel Chromium/Nickel Aluminium			KX
N	Nicrosil/Nisil			NX NC
T	Copper/Constantan			TX
Vx	Copper/Constantan (Low Nickel)			KCB
U	Copper/Copper Nickel			RCA SCA

Table 18.4 – International colour code for thermocouples' extension grade wires

Thermocouple		*Conductors*	*Temperature Range (°C)*	*Seebeck Coefficient*	*Application Environments*
Type	*Code*				
NiCr-CuNi	*E*	*Chromel, Constantan*	*-200 to +900*	*60 µV/°C*	*Oxidising, inert, vacuum*
Fe-CuNi	*J*	*Iron, Constantan*	*0 to +750*	*51 µV/°C*	*Vacuum, oxidising, reducing, inert*
Cu-CuNi	*T*	*Copper, Constantan*	*-200 to +371*	*40 µV/°C*	*Corrosive, moist, subzero*
NiCr-NiAl	*K*	*Chromel, Alumel*	*-200 to +1260*	*40 µV/°C*	*Completely inert*
	N	*Nicrosil, Nisil*	*0 to +1260*	*38 µV/°C*	*Oxidising*
PtRh10-Pt	*S*	*Platinum(10% Rhodium), Platinum*	*0 to +1480*	*11 µV/°C*	*Oxidising, inert*
PtRd30-PtRd6	*B*	*Platinum (30% Rhodium), Platinum (6% Rhodium)*	*0 to +1820*	*8 µV/°C*	*Oxidising, inert*
PtRh13-Pt	*R*	*Platinum (13% Rhodium), Platinum*	*0 to +1480*	*12 µV/°C*	*Oxidising, inert*

Table 18.5 – Types of thermocouple available

18.3.1 Thermocouples *Type-K, -J* Characteristics

A reference table and characteristics for thermocouples (TC) type K and J are illustrated in Table 18.6 and Figure 18.14. A more detailed data sheet is provided in Appendix 8.

Temperature (°C)	*Output Signal (mV DC)*	
	J	*K*
0	0	0
100	4,09	5,27
200	8,14	10,78
500	20,64	27,39
750	31,21	42,18

Table 18.6 – TC-J and TC-K reference table

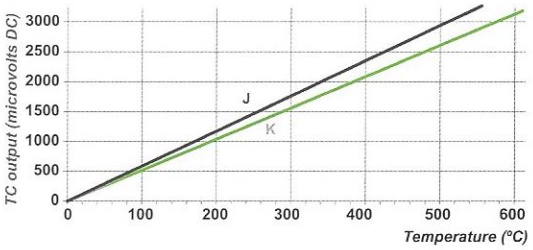


Figure 18.14 – TC-J and TC-K characteristics

18.3.2 Exhaust Gas Temperature Monitoring

Figure 18.21 represents a MAN B&W engine exhaust monitoring scanner which is connected to a PLC input. BM16 incorporates input from eight cylinder exhaust gas thermocouples, turbocharger in/out thermocouples and a Pt 100 for cold-junction compensation (CJC). If Pt 100 fails, it would lead to errors in all the monitoring channels.

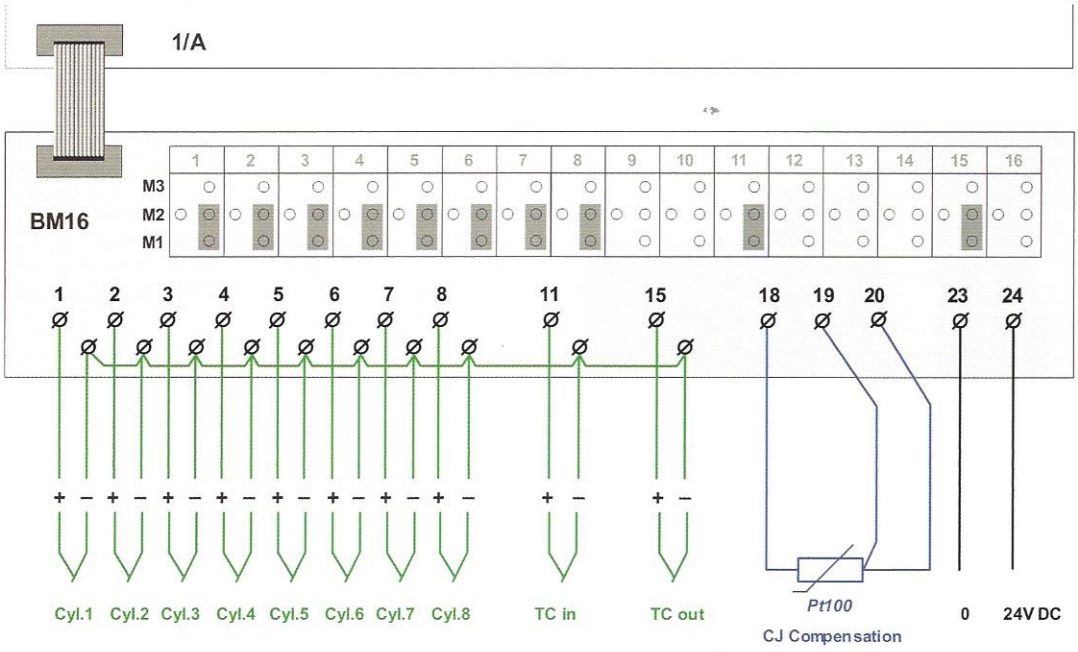


Figure 18.15 – MAN exhaust gas temperature monitoring

18.3.3 Troubleshooting Thermocouples

If a thermocouple (TC) signal fails, it is suggested that the following checkup procedure is used to verify that the TC itself is functioning properly:

- Test the TC output signal with a DMM across the sensor terminals. Compare the obtained data with the relevant characteristics and verify the signal related to the temperature
- determine that the sensor or the equaliser wiring is not short circuited to the ground, by measuring continuity with an earthed terminal
- by using a process calibrator, the *mV* signal can be simulated instead of the TC output signal. This will clarify if the control unit has malfunctioned or not.

Figure 18.16 – Measuring TC-K output with DMM

Common deficiencies noted for TC sensors are incorporated in Table 18.7.

Problem	*Possible Cause*
Temperature reading too low	• *Short circuit* • *Moist at thermocouple* • *Moist at connector* • *+ and – of thermocouple switched* • *Compensation resistor (Pt 100) incorrectly connected*
Temperature reading too high	• *Open circuit due to cable break* • *Loose connector*

Table 18.7 – Common problems related to thermocouples

18.4 Pressure Transducers Pressure Transmitters

A pressure transducer converts pressure into an analogue electrical signal. Although there are many types of pressure transducers, one of the most common is the strain-gauge base transducer. The conversion of pressure into an electrical signal is through the physical deformation of strain gauges which are bonded into the diaphragm of a pressure transducer and wired in a wheatstone bridge configuration. Pressure applied produces a deflection of the diaphragm importing a strain on the gauge. Electrical resistance is proportional to the pressure.

Pressure transducers are generally available with three types of electrical output: millivolt, volt and 4-20 mA.

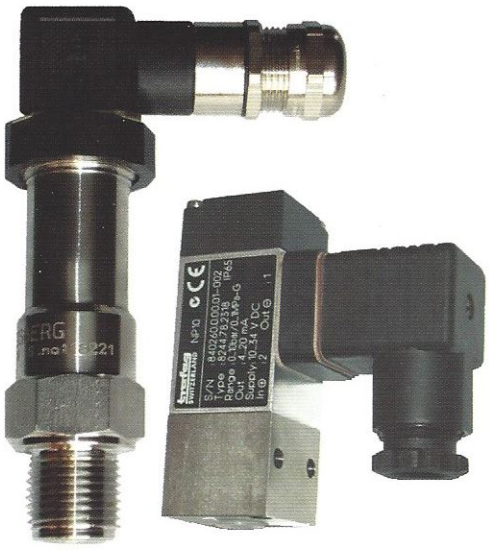


Figure 18.17 – 4-20 mA pressure transducers

18.4.1 Millivolts-Output (mV) Pressure Transducers

Pressure transducers with millivolt-output are normally the most economical and the actual output, nominally around 30 mV, is directly proportional to the pressure transducer input power or excitation.

The transducer should not be located in an electrically noisy environment. This is because the output signal is low (and is susceptible to electrical interference), the distances between the transducer and readout instrument should also be relatively short.

18.4.2 Volts-Output Pressure Transducers

Voltage output transducers provide a much higher output than a millivolts' transducer which is not usually a direct result of excitation. The output is normally 0-5 V or 0-10 V. This means that unregulated power supplies are often sufficient, as long as they fall within a specified power range. Due to their higher voltage output they are less susceptible to electrical noise than mV pressure transducers and more suited to an industrial environment.

18.4.3 4-20 mA Pressure Transducers

Of the three types of pressure transducers, the 4-20 mA is least affected by electrical noise or resistance in the signal wires. They are best suited where the signal is transmitted over long distances.

Most pressure transducers feature an accuracy of 0.25% or higher, but high stability and high accuracy pressure transducers can offer errors as low as 0.05%.

The diagram symbol and wiring sample for a 4-20 mA pressure transducer is shown in Figure 18.18a and Table 18.8. The transducer is shown as a P/I (Pressure to current convertor) wired using two conductors.

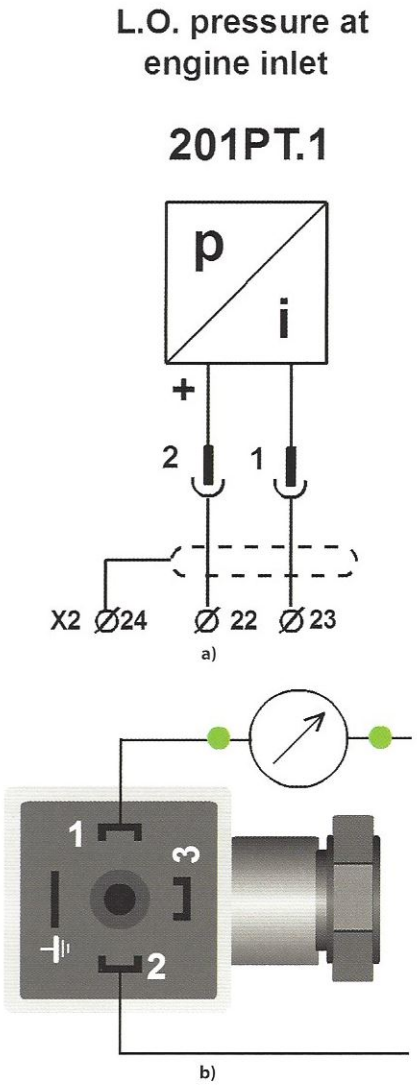


Figure 18.18 – a) Pressure transducer wiring example (Wärtsilä L38 engine)
b) 4-20 mA transducer plug GDA3YD

Tag Nr.	Tag Name	Description	Sensor	Channel Type	Term. Board	Source/ Dest
10125	101PT	Fuel oil pressure at inlet	4-20 mA	AIN	TB01B-9A TB01B-9C	CC4-2 M-101P1+
10126	201PT.1	LO pressure at inlet	4-20 mA	AIN	TB01B-10A TB01B-10C	CC4-4 M201P1+

Table 18.8 – Pressure transducer data sheet (extraction from Wärtsilä L38 LCS PLC manuals)

18.4.4 The Ratio Between Pressure and Current

If a pressure controller registers a deviation in the pressure it will only operate correctly once the transducer has been calibrated correctly to the intended pressure limit (see characteristics shown in Figure 18.19).

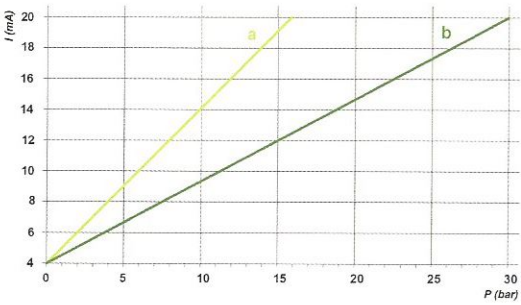


Figure 18.19 – 4-20 mA pressure transducer characteristics:
a) 0-16 bar pressure transducer
b) 0-30 bar pressure transducer

Most manufacturers supply transducers coupled with the respective transmitter and prohibit readjusting calibration potentiometers. If either the transducer or transmitter become damaged, it is advised that the couple (transducer-transmitter) is replaced.

18.4.5 Troubleshooting 4-20 mA Pressure Transducers

If a 4-20 mA transducer output signal fails, the following procedure should be followed to verify that the sensor is in order:

- Test the transducer with a DMM by opening one conductor and connecting the DMM in series as shown in Figure 18.20
- verify that the sensor mA signal is correct
- determine that the transducer wiring has no short circuit to the ground (by measuring continuity with earthed terminals)
- by process calibration a 4-20 mA output signal can be simulated instead of using the transducer output signal, to determine whether the control unit has malfunctioned.

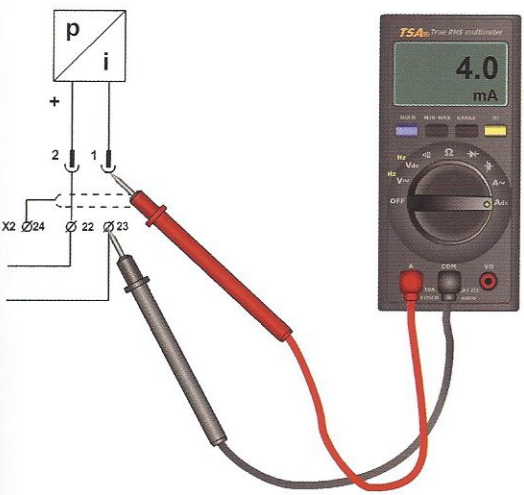


Figure 18.20 – Measuring 4-20 mA transducer's output signal

18.4.6 Pressure Transmitters

The pressure transmitters transfer the 4–20 mA signal received from pressure transducers to the control circuit. As mentioned before, the transmitter and transducer are calibrated to one another and built into a relative couple. To calibrate the transducer mA-output signal to a control unit, as a ratio to pressure range, two potentiometers are used: Zero (OffSet) and Range (Span), to calibrate values of 0% and 100% of the signal respectively.

A transmitter can also be a part of a transducer (inbuilt type) or part of a PLC (4-20 mA adaptor or 4-20 analog input module). Some examples of transmitters are illustrated in Figures 18.21 to 18.24.

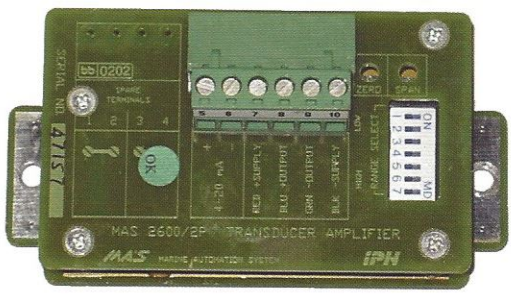


Figure 18.21 – MAS transmitter

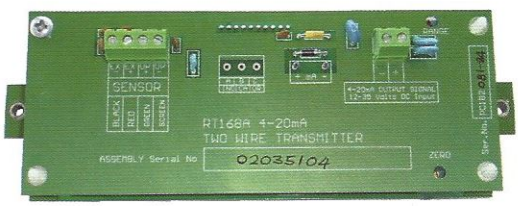


Figure 18.22 – SCANA transmitter

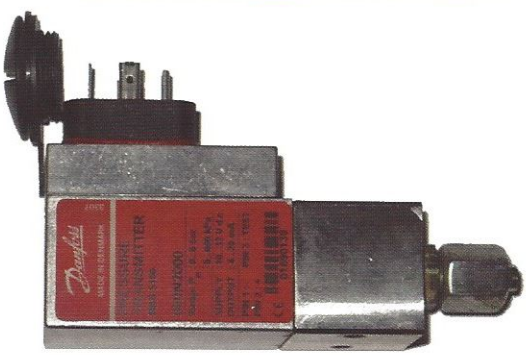


Figure 18.23 – DANFOSS transducer with inbuilt transmitter

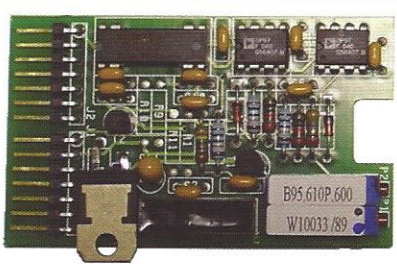


Figure 18.24 – Wärtsilä LCS 4-20 mA adaptor

18.5 Speed Monitoring Sensors

There are two types of speed sensor: magnetic pickups and proximity switches. Although they look similar there are significant differences between the operating principles and troubleshooting approach. This section is intended to explain the basic differences.

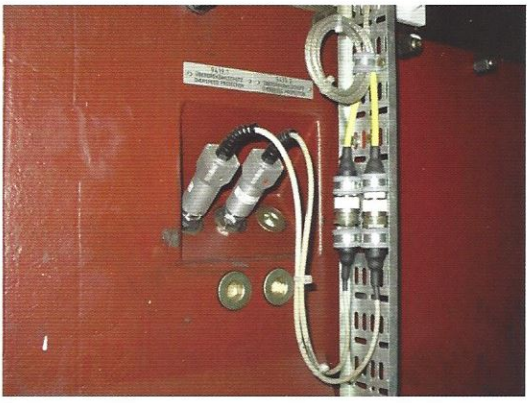


Figure 18.25 – Overview at MaK engine magnetic pickups

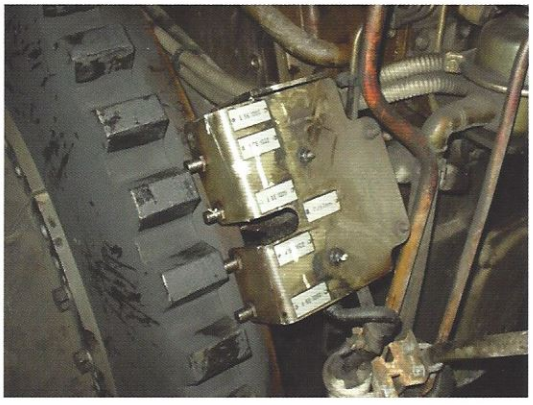


Figure 18.26 – Overview at MAN B&W engine proximity switch probes

18.5.1 Electromagnetic Speed Sensors

Electromagnetic speed sensors are also known as Magnetic Pickups (MPUs). The operating principle is based on the fact that as the ferromagnetic pole wheel passes, the speed sensor head will alter the magnetic field in a magnetically biased coil (Figure 18.27). Based on the law of induction, an AC output voltage is generated, with a frequency and amplitude proportional to the speed of the pole wheel.

The output voltage of the magnetic pickup can be affected by the following factors:

- Voltage increases as the surface speed of the monitored magnetic material increases
- voltage decreases as the air gap between the magnetic head and surface of the gear tooth is increased
- voltage waveform is determined by the size and shape of the gear tooth in relation to the size and shape of the pole piece.

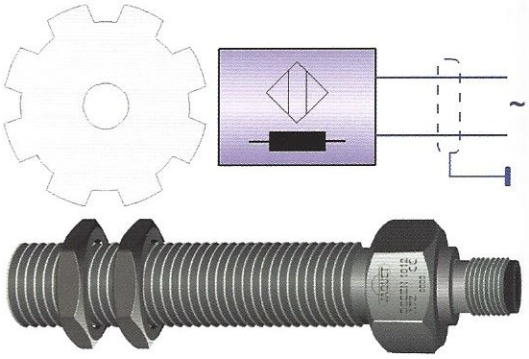


Figure 18.27 – Magnetic pickup

Large engines usually have a larger air gap between the speed pickup probe and the monitored gear.

18.5.2 Ferromagnetic Speed Sensors with Line Amplifier

Proximity speed switches operate well on large engines as they can operate with a large air gap and low surface speeds.

The principle of operation is based on the fact that a ferromagnetic pole wheel passing the sensor head influences the voltage in an integrated HAL element magnetic sensor (Figure 18.28). The voltage is amplified to a square wave signal with the frequency dependent on the pole wheel speed. When a flywheel tooth is within the sensing range of a proximity switch probe, the output of the switch is nearly equal to the supply voltage. On passing the tooth, the sensor output switches to zero volts until another tooth comes into proximity of the sensor head. The amplitude approximates to the supply voltage and is independent of speed.

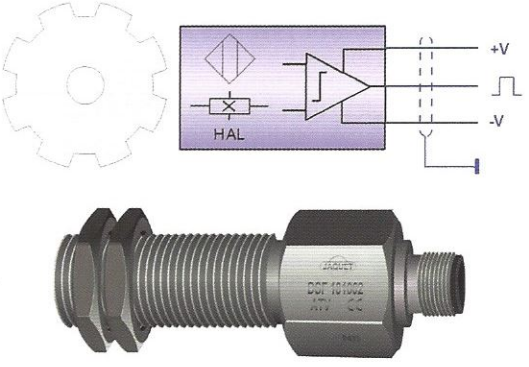


Figure 18.28 – Proximity speed switch

Proximity switches require a constant external DC voltage power supply. Depending on the proximity switch probe manufacturer, it can be within a range between 10-30 V and is always applied even when an engine is stationary. This may be from the same supply source as the power for the engine control and safety system. The maximum current rating for proximity switches is 80 mA, but the actual current is much less and depends on the external load.

18.5.3 Speed Pickups' Diagram Definition and Troubleshooting

There are various symbols to define speed pickups in diagrams (Figure 18.29), they are often represented as RPM-to-Frequency (n/f) converters (Figure 18.30).

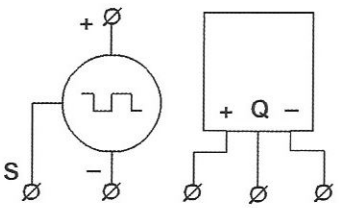


Figure 18.29 – Speed pickup symbols

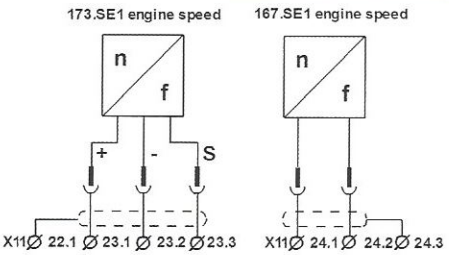


Figure 18.30 – Speed pickup wiring for Wärtsilä L38 engine

The difference between the two types of speed sensors, magnetic pickup and proximity, are as follows:

Magnetic Pickup (MPU)

- Small gears and high surface speeds
- high frequencies 1kHz and more
- no power supply needed
- sensor output signal +/- 1.5 V AC (RMS).

Proximity sensor (PU)

- Large gears and slow surface speeds
- max switching frequency is 500 Hz
- needs a power supply 10-30 V DC.

As both types of speed sensors are called pickups, it is important to determine which type it is. If it cannot be determined for example by the manufacturer's manual, catalogues etc, the easiest way is to count the number of conductors connected to the sensor on the diagram (Figure 18.30):

- 3-wires - Proximity speed sensor (173.SE1)
- 2-wires - Magnetic pickup (167.SE1).

As an MPU has a permanent magnetic field, it can be also checked by bringing magnetic material in proximity of the magnetic head.

When determining the type of speed probe for installations, the manufacturer's data tables are helpful. An example of a table is given in Table 18.9 for Wärtsilä L38 engines.

On observing a deficiency in speed monitoring and to establish if an employed proximity speed sensor is failed and has to be replaced, the power supply across 23.1(+) and 23.2(-), and the frequency across 23.3 (S) and 23.2 (-), should be measured (Figure 18.30).

If no voltage is detected or the voltage level has dropped below the limits defined by the manufacturer, eg an open conductor or a power supply earth failure, the frequency would be nil or the signal would become erratic.

The procedure for checking the proximity speed switch is illustrated in Figures 18.31 and 18.32.

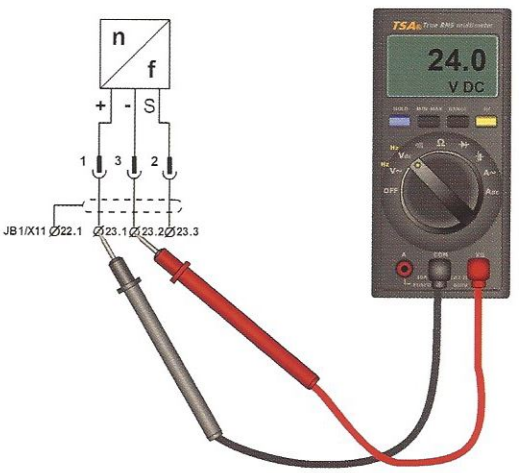


Figure 18.31 – Measuring voltage for proximity speed switch

Tag Nr.	Tag Name	Description	Sensor	Channel Type	Term. Board	Source/Dest.
10711	173SE.1L	Engine RPM indication-1	Pulse	PIN	TB07A-11C TB07A-11B TB07A-11A	CP2-1 CP2-2 CP2-3
10712	173SE.1H	Engine RPM overspeed-1	Pulse	PIN	TB07A-12B TB07A-12A	
11009	173SE.2 L	Engine RPM indication-2	Pulse	PIN	TB10A-9C TB10A-9B TB10A-9A	CP2-4 CP2-5 CP2-6
	167SE.1	Engine RPM for WW721	MPU	PIN		WW721: 17,18

Table 18.9 – Speed probes' data sheet (extraction from Wärtsilä L38 LCS PLC data sheet)

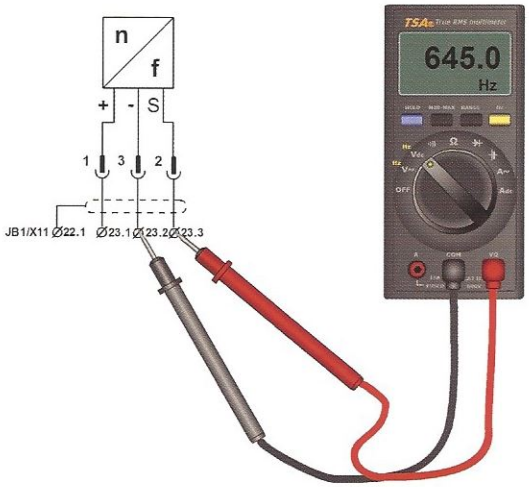


Figure 18.32 – Measuring frequency output from proximity speed switch

To confirm that an MPU is in order, Figure 18.30, both the output voltage and frequency should be measured from the same terminals 24.1 and 24.2.

For both types of speed probes, if the frequency carrying conductor becomes short circuited to ground, some PLC-based applications have been known to interpret this condition as being related to overspeed and can shut the engine down. Restarting became impossible until the fault was rectified.

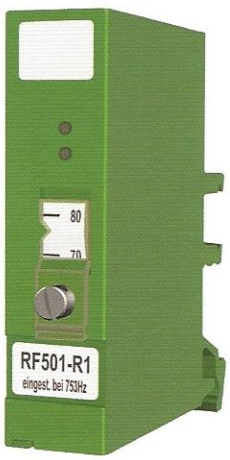
18.5.4 Speed Monitoring Relays

The purpose of a speed monitoring relay is to measure the frequency taken from the speed pickup, compare it with the adjusted set point (0-100% of relay's frequency range) then produce an output by using the relay's internal contacts in the event of reaching a set point.

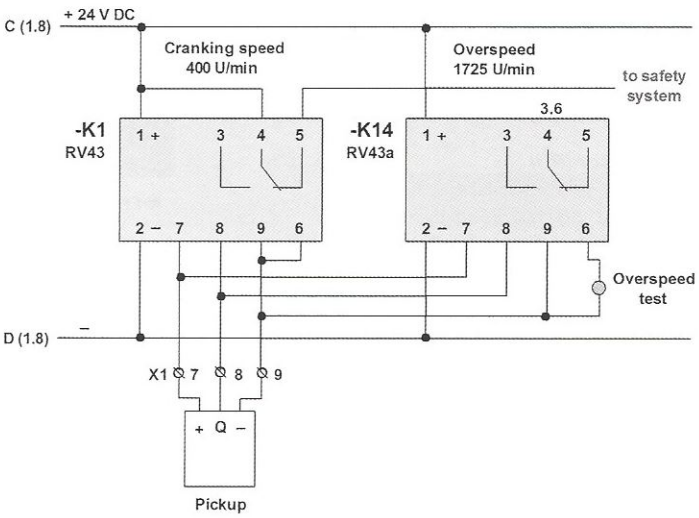
The example given in Figure 18.33 illustrates the speed control for a Piller auxiliary engine. The frequency from one of its speed proximity sensors is shared in parallel by two speed monitoring relays (K1 and K14). One relay acts as the ignition speed relay to cut off the starting air supply as soon as the cranking speed is reached. The safety system is engaged after the engine has reached a predetermined RPM. The second relay is used for an overspeed related safety function. As a consequence, the relay set points are different.

18.5.5 Frequency to Current (F/I) Converters

The example in Figure 18.34 represents an extract from a MAN B&W engine speed monitoring diagram. U1 and U2 are frequency-to-current converters (Figure 18.35) which converts the frequency signals received from proximity speed switches into a 4-20 mA signal (required as an analogue input for ABB PLC).



a)



b)

Figure 18.33 – a) Speed monitoring relay NORIS RF501-R1
b) R.Janssen control for Piller engines (extraction from original diagram)

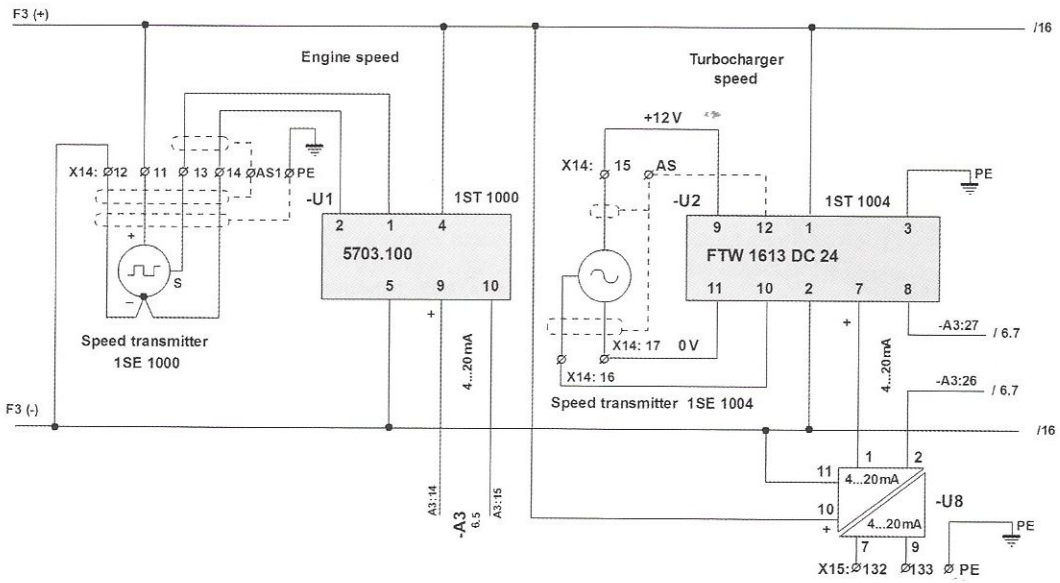


Figure 18.34 – MAN B&W speed monitoring section

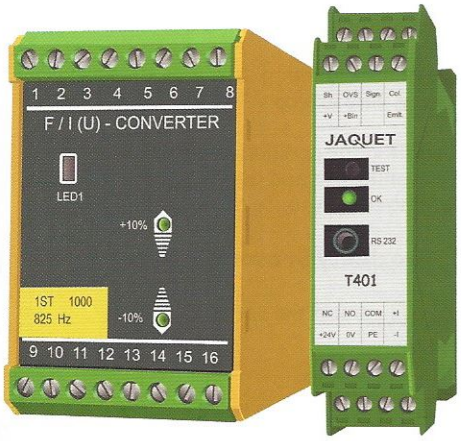


Figure 18.35 – MAN B&W engine control system speed converters

18.6 Proximity Sensors

18.6.1 Capacitive Sensors

Capacitive sensors are able to detect most materials at distances of up to a few centimeters, ie by recalling the basic relationship for capacitance:

$$C = A \times k/d$$

Where:

C = *capacitance (Farads)*
k = dielectric constant
A = area of plates
d = distance between plates (electrodes).

In the sensor, the area of the plates and distance between them is fixed, but the dielectric constant of the space around them will vary as different materials are brought near to the sensor. An illustration of a capacitive sensor is shown in Figure 18.36. An oscillating field is used to determine the capacitance of the plates, when this changes beyond a selected sensitivity the sensor output is activated.

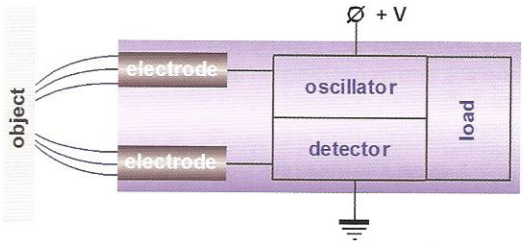


Figure 18.36 – Capacitive sensor outline

Capacitive sensors are effective when using insulators that have relatively high dielectric coefficients. Metals are also an effective conductive material in the target and appear as electrodes, increasing the capacitance, as seen in Figure 18.37. In total the capacitance changes are normally in the order of *pF*.

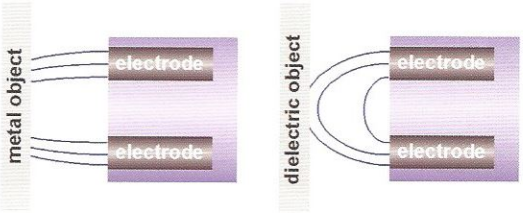


Figure 18.37 – Dielectrics and metals increase the capacitance

The sensor is normally constructed in rings (Figure 18.38) and is made up of the capacitor electrodes (two inner rings) and an outer ring to compensate for variations. The compensator ring helps to prevent over sensitivity to contaminants such as oil or dirt.

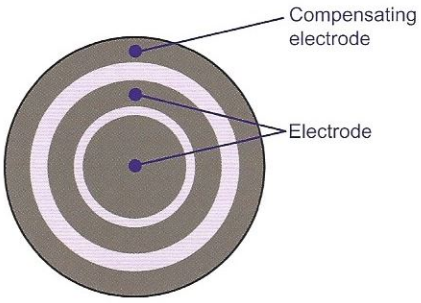


Figure 18.38 – Electrode arrangement for capacitive sensors

The size of the sensors, varying from a few milimetres to a few centimetres, establishes the accuracy and range. The larger the size, the greater the range, but accuracy will be lower.

18.6.2 Inductive Sensors

Currents induced in the magnetic fields of nearby metallic objects are detected by inductive proximity sensors. These sensors comprise an oscillator whose windings constitute the sensing face. By generating an alternating magnetic field in front of the windings, Figure 18.39, as metallic objects approach the changing magnetic field, current will be induced in the object. The resultant current flow creates a new magnetic field that opposes the original field.

This results in a change of inductance in the inductive sensor coil, which if measured identifies a nearby metal. This causes the output driver to operate, and depending on the sensor type, a normally open or closed signal is produced for the control system.

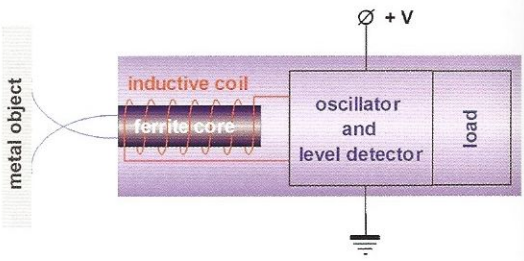


Figure 18.39 – Inductive proximity sensor outline

By creating a high frequency field, eddy currents are created as the target object approaches the field. Due to resistance, the currents will consume power, losing energy and reducing the signal amplitude. When sufficient change is detected, the switch changes state.

The sensor detects objects which are a few centimetres around the end (Figure 18.40). To reduce this area and provide better direction, a shield (metal jacket) is fitted around the sides.

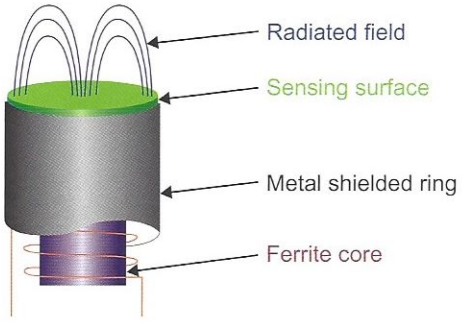
In practice, most objects which are detected are made of steel and are of a size equal to or greater than the sensing face of the sensor.

The range of the induction proximity sensors' application is very extensive and includes:

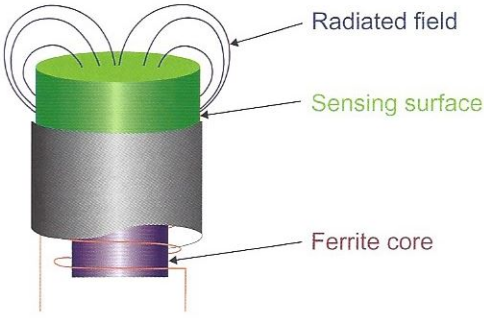
- Monitoring the position of machine parts (cams, end stops and gears etc)
- counting the presence of metal objects, etc.

18.6.3 Proximity Sensor Output

Table 18.10 illustrates the various proximity sensor output signals.



a)



b)

Figure 18.40 – a) Shielded proximity sensor

b) Unshielded proximity sensor

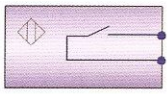
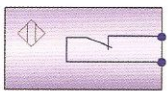
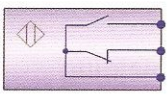
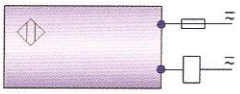
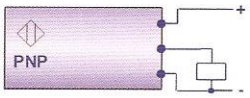
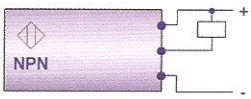
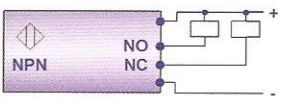
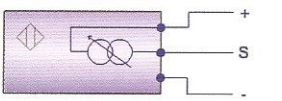
Sensor symbol	Output type/details
	Normally open (NO). Sensor's output changes to the closed state when an object is present within the object detection zone.
	Normally closed (NC). Sensor's output changes to the open state when an object is present within the object detection zone.
	NO+NC. Sensor output incorporates both NO and NC signals.
	2-wire non-polarised NO or NC. Sensor is wired in series with load to be switched.
	3-wire type NO or NC, PNP (positive negative positive) or NPN (negative positive negative). Sensor comprises two wires for the DC supply and a third wire for the output signal: PNP type switches positive side to the load.
	NPN type switches negative side to the load.
	4-wire type NO or NC, PNP or NPN. Sensor incorporates two outputs PNP or NPN type; 4-wire multifunction programmable NO or NC, PNP or NPN.
	Analogue output signal. Sensor converts approach of metal object towards the sensor's head into either 4... 20 mA or 0... 10 V DC signal proportional to the distance between the object and sensor's head.

Table 18.10 – Proximity sensor output

18.6.4 Fuel Rack Transmitter

An inductive proximity sensor with dual analogue output: 0-10 V DC and 0-20 mA made by TURCK (Figure 18.41) is used as an engine load monitoring sensor for Wärtsilä and MaK engines. It is fitted close to the fuel rack linkage to adjust the fuel injection, in front of a monitoring cam (Figure 18.42).

Figure 18.41 – Fuel rack sensor

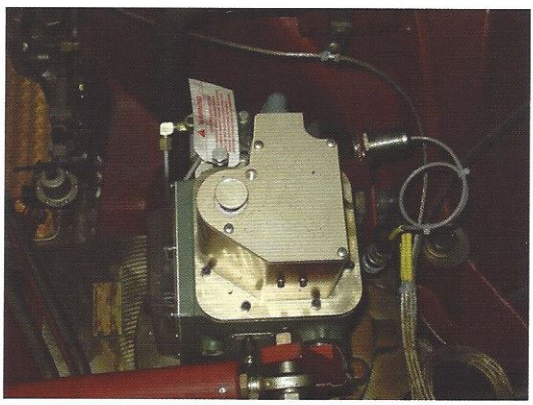


Figure 18.42 – M43 MaK engine fuel rack sensor

The sensor measures the air gap between the sensor head and the adjustable cam surface giving an output signal acquired by a propulsion control system. The diagram symbol, wiring details and characteristics are shown in Figure 18.43.

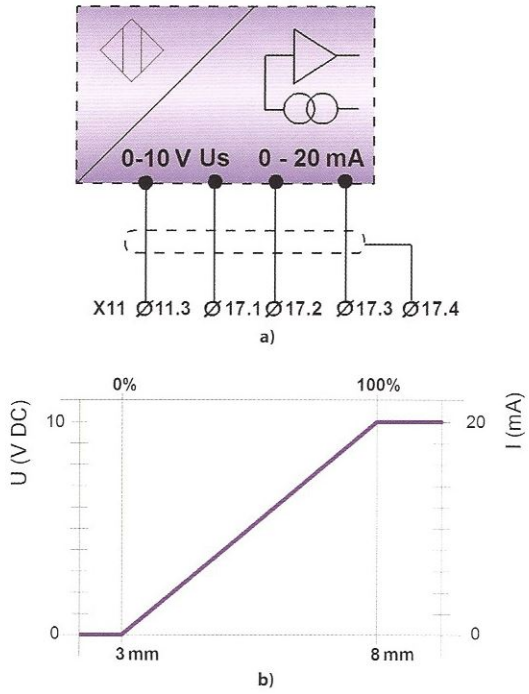


Figure 18.43 – a) Turk Bi10 diagram definition
b) Analogue output characteristic

The sensor output signal is determined by calibration. To function correctly the air gap must be adjusted to 3 mm for a 0% load. This corresponds to a 0 V or 0 mA output signal that is transmitted to the control system. The cam surface shape is machined so that by moving the fuel rack to 100%, the main engine load increases the gap between the sensor head and cam by 8 mm producing 10 V or 20 mA, as shown in Figure 18.43b.

18.7 Feedback Potentiometers

Potentiometers measure the angular position of a shaft using a variable resistor. The potentiometer is a resistor, normally made with a thin film of resistive material.

A moving contact called a wiper can be moved along the surface of the resistive film with the shaft (Figure 18.44). As it moves towards one end there will be a change in resistance which is proportional to the distance moved. If a voltage is applied across the resistor (terminals 1 and 2), the voltage at the wiper (3) will interpolate the voltages at the resistor ends.

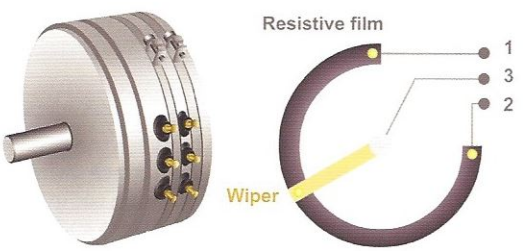


Figure 18.44 – Potentiometer's outline

The potentiometer shown in Figure 18.44 is being used as a voltage divider. When a DC voltage is applied across terminals 1 and 2, if the wiper rotates the output voltage (1-3 or 2-3) will be proportional to the angle of rotation.

Potentiometers are widely used as feedback sensors for a variety of controls such as controllable pitch propellers, steering gear, thrusters and cranes. The majority of problems with potentiometers relate to worn out carbon tracks, where contact with the potentiometer's wiper weakens and the feedback signal to the control system is lost or reduced.

18.8 Sensor Wiring and Shielding

Due to the extremely low level of signal, analogue input modules using sensor output signals are particularly vulnerable to electromagnetic noise or signals induced by other conductors or devices. To avoid any possible signal interference, signal cables occupying the same cable tray, trunk or conduit with power cables must be screened. The cable screen should be grounded at only one end of the cable. If the screen is grounded at both ends, a ground loop is created and ground currents could result in faulty operation. Figure 18.45 represents cables being used for automated appliance wiring.

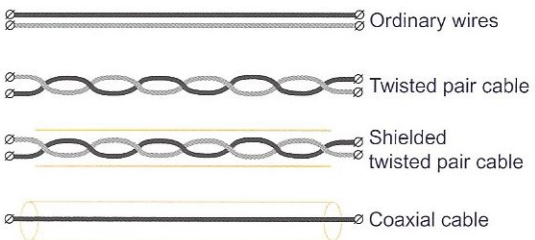


Figure 18.45 – Sensor wiring samples

As a number of breakdowns with ships' automation are related to sensor wiring, it is suggested that this is checked first when troubleshooting. Figures 18.46 to 18.51 illustrate many common problems affecting main engine automation sensor wiring (short circuits with screening, cross linking of conductors between two different sensors, etc).

Figure 18.46 – Thermocouple cable. Worn out outer armour (conductors cross-linking)

Figure 18.47 – Main engine governor cable damaged outer sleeve

Figure 18.48 – Sensor cables not secured to cable tray

Figure 18.49 – Sensor cable which has been damaged by not being secured to a cable tray

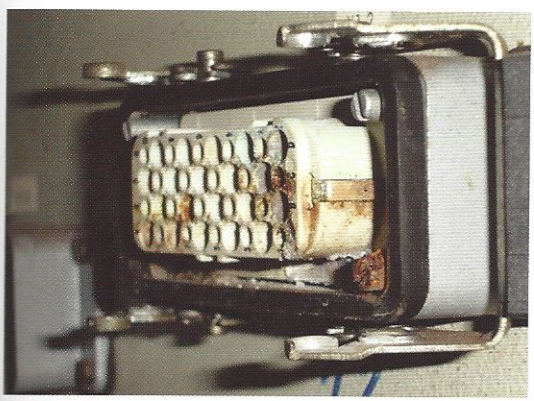


Figure 18.50 – Sensor plug contaminated by water leakage (cross-linking of sensor wiring)

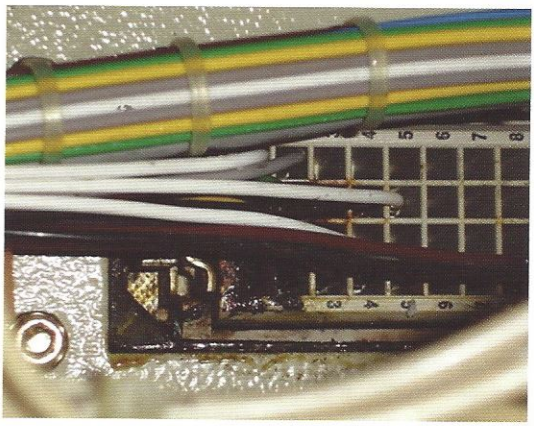


Figure 18.51 – Contaminated sensor connector (cross-linking of conductors)

18.9 Analog Signal Converters

Nearly every process on a modern ship includes a control system that receives data by analogue signals, the data is evaluated and sets the respective parameters. When transmitting analogue signals, numerous problems may arise that interfere or block a signal causing the PLC application to hang up.

Some processing problems are listed below.

Signal conversion. At times, the available signals cannot be processed by the controller or the actuator. If this is the case the signal converters are required to convert the input signal to the desired output signal (Figure 18.52).

Signal amplification. If the long wiring or high burdens are managed, the signal must be amplified. Analogue converters are used as they require low input power but deliver high output power. Therefore there are no restrictions for the converters' position on the line, ie it can be used as follows:

- For signal refreshing at the end of the cable (low input power)
- and/or for signal amplification at the beginning of the cable run (high output power).

Figure 18.52 – Signal convertors

Signal filtering

On long cable runs or in rough environments, signals are exposed to high electromagnetic interferences. Subject to specific requirements, analogue signal converters are available providing reliable suppression of such interference by using an input low-pass filter.

Signal separation

- **Protection against overvoltage** – The increased use of micro-electronics and PLCs make the controls more sensitive to overvoltages caused by lighting discharges or switching processes. Suppression diodes are incorporated within the input of analogue signal converters, allowing the converters to arrest overvoltages with low energy levels (resulting from switching processes). The products provide electrical isolation between the input, output and supply circuits, protecting the output connect controller.
- **Protection against ground loops** – If a component has an earth fault, the measuring signals can be affected. In this case, certain parts of the signal are transmitted via the earth and not along the analogue transmission line, causing incorrect evaluation of the signal. Electrical isolation between the input and output rectify the problem.

Signal conversion is required as follows (Figure 18.53 to Figure 18.56):

- Signals of RTD sensors
- thermocouple signals (exhaust gas bearing temperature, cylinder liner temperature etc)
- speed pick up signals
- RMS value of currents and voltages (proximity sensors and feedback potentiometers).

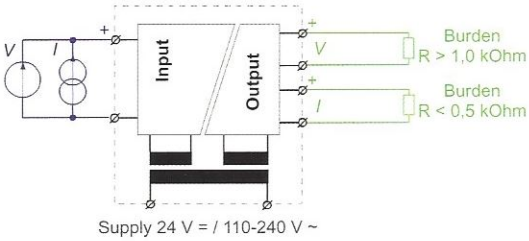


Figure 18.53 – Analogue standard signal converter

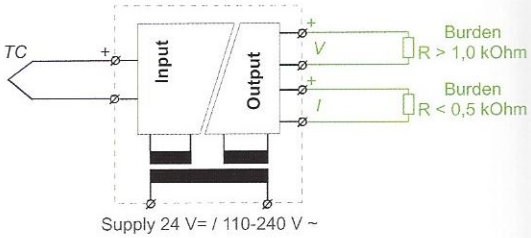


Figure 18.54 – Temperature signal converter for thermocouples

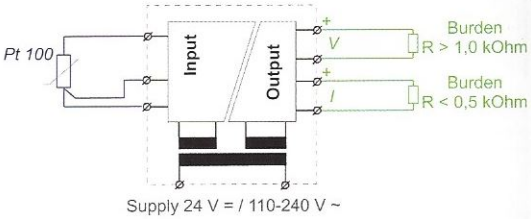


Figure 18.55 – Temperature signal converter for RTD sensors

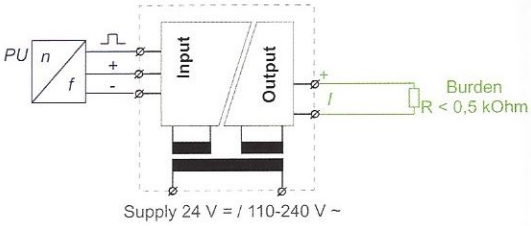


Figure 18.56 – Frequency signal converter for proximity speed sensors

19 Intrinsic Safety

19.1 Introduction

Under normal working conditions, electrical equipment can creates tiny internal sparks which can ignite flammable substances that are present in the ambient air if an oxidiser is present, eg arcing between switch contacts, electrostatic spark discharges or arcing between live conductors and earth. Therefore, spaces where the concentration of flammable gas, vapour or dust is expected to be high will be defined as a hazardous location.

An intrinsically safe system assumes that the fuel and oxidiser are simultaneously present in the ambient air. The system is designed so that the electrical or thermal energy of a particular instrument loop is never high enough to create ignition.

The simplest way to avoid any explosions is to minimise the amount of electrical equipment installed in hazardous areas, by either keeping the equipment out of the area altogether or making the area less hazardous by improving ventilation. There are a number of different structural techniques employed in the ship building industry intended to prevent explosions caused by electrical equipment in hazardous areas. Some techniques (eg flameproof enclosures) were established some time ago, but others, such as intrinsic safety, are the result of recent scientific developments in the electronic circuit design for hazardous areas.

Intrinsic safety (IS) can be defined as the safe operation of electronic equipment in explosive atmospheres. The IS-concept was developed for the safe operation of process control instruments in hazardous areas (Figure 19.1). This must be adhered to on ships which are carrying a hazardous cargo.

It was internationally agreed that explosion protected equipment should be identified with the symbol illustrated in Figure 19.2 and a letter indicating the type of protection used.

Figure 19.2 – Explosion protection equipment symbol

The following types of protection are defined for ship installations:

Exd – flameproof enclosure
Exi – intrinsic safety
Exe – increased safety
Exn – non-sparking
Exp – pressurisation
Exs – special protection.

Electrical equipment can also be marked with the prefix E (for instance EExi) which denotes compliance with European Standards.

19.2 Zener Barriers

Zener Barriers are intrinsically safe as they are designed not to contain any components that will produce sparks or be able to hold enough energy to produce a spark. This is achieved by ensuring that only low voltages (less than 30 V) and currents (less than 50 mA) enter the hazardous area, and that all the electric supply and signal wires are protected by zener safety barriers. The basic design of an intrinsic safety barrier uses Zener Diodes to limit voltage, resistors to limit current and a fuse (Figure 19.3).

In the event of a unexpected high voltage from a non-hazardous area, the Zener diodes will conduct. While conducting, the current level is designed to blow the fuse which isolates the circuit to maintain safety in a hazardous area.

If equipment short circuits in a hazardous area, the in-line resistor will limit the size of the fault current while the fuse blows. Two or three Zener-resistor

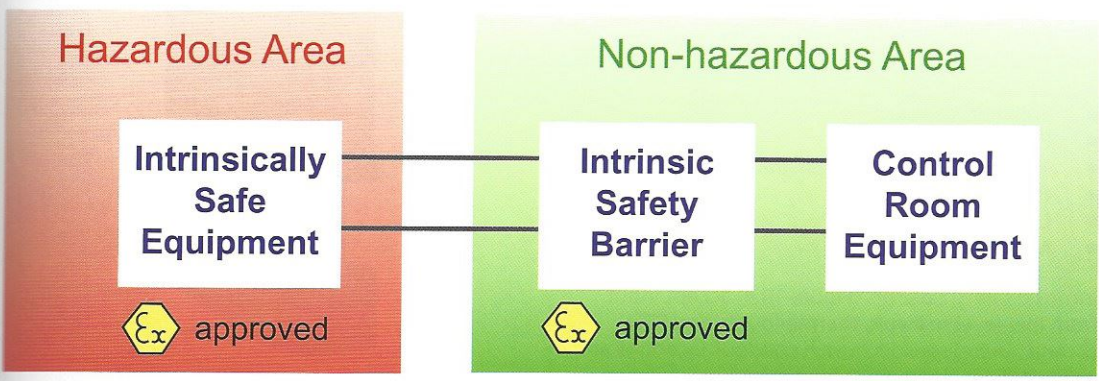


Figure 19.1 – Intrinsically safe application

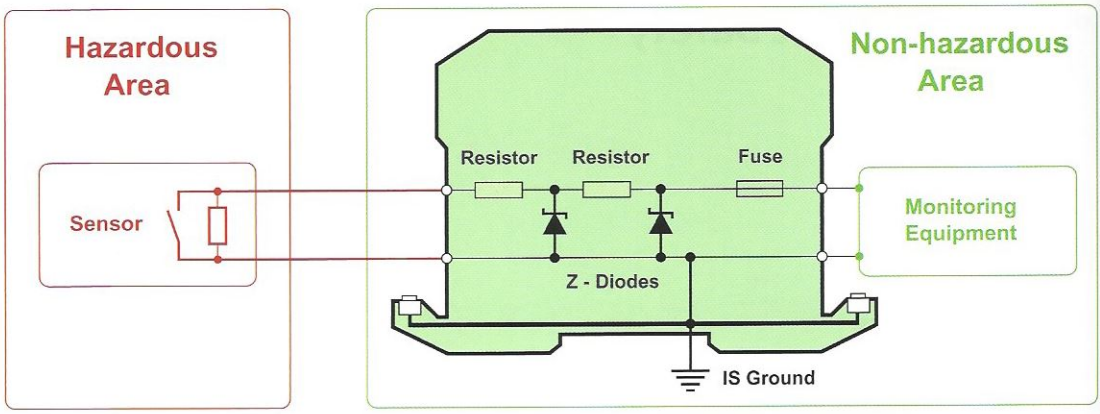


Figure 19.3 – Positive single channel Zener Barrier with negative ground for digital sensor

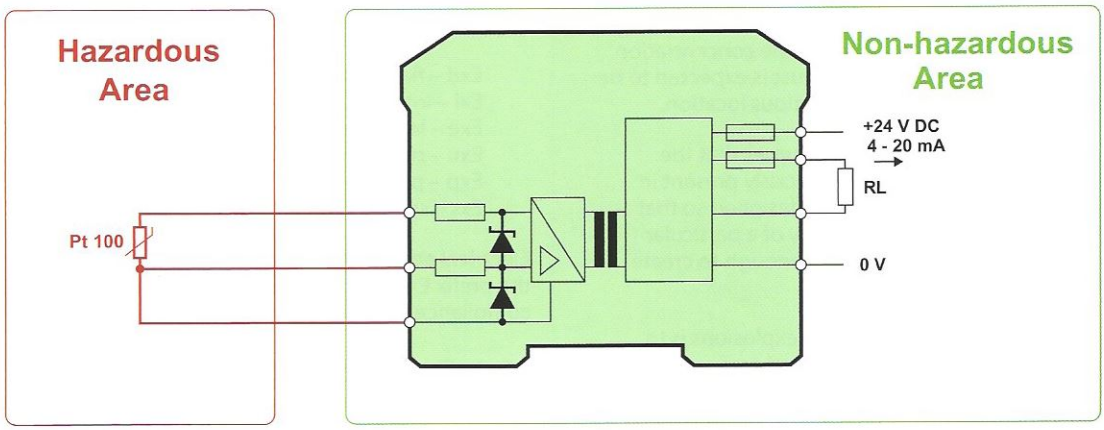


Figure 19.4 – Isolation barrier for temperature monitoring analogue sensor (RTD)

combinations are used within a barrier to provide back-up voltage anchors while the fuse is blowing.

19.3 Intrinsically Safe Applications

Most applications require a signal to be sent out from or into the hazardous area. The equipment mounted in the hazardous area must first be approved for use in an intrinsically safe system. The barriers designed to protect the system must be mounted outside the hazardous area in a designated non-hazardous or safe area where the hazard will not be present.

Equipment designed for use in hazardous areas with intrinsically safe barriers includes:

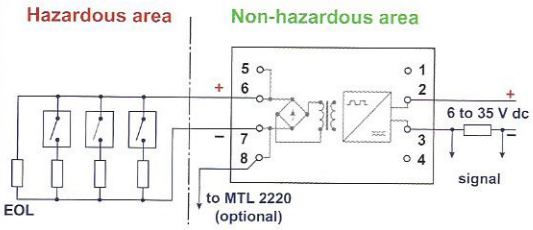
- 4 - 20 mA/dc Two-Wire Transmitters
- Thermocouples
- RTDs
- Pressure, Flow and Level Switches
- Smoke detectors
- I/P Converters
- Solenoid Valves
- Proximity Switches
- Infrared Temperature Sensors
- Potentiometers
- LED Indicating Lights
- Magnetic Pickups.

Intrinsic safety isolators (Figure 19.4) accept input from low-level millivolt, thermocouple and RTD (2- and 3-wire) sensors from hazardous locations and convert them into a 4–20 mA signal.

The isolators are mounted in a type approved enclosure within a non-hazardous area, providing an intrinsic safety barrier.

MTL (Measurement Technology Limited) DC isolators (Figure 19.5) are used in smoke detection systems. Their purpose is to isolate the power supply for zone detectors located in hazardous areas, such as holds for carrying hazardous cargo, battery rooms, paint lockers, etc. EOL is an End of Line resistor in a zone.

a)



b)

Figure 19.5 – a) MTL intrinsic safe isolators
b) Use of IS isolators for holds' smoke detection system

19.4 Approvals and Regulations

As in most fields of electrotechnology, different countries have approached the standardisation and testing of equipment for hazardous areas in different ways. As world trade increases, international standards are slowly converging so that a wider range of acceptable techniques can be approved by national regulatory agencies (Table 19.1).

These standards require intrinsically safe wiring to be separated from non-intrinsically safe wiring. Intrinsically safe wiring, terminals and raceways must also be clearly labelled. Other factors, such as earthing and shielding requirements, are also considered.

The installation of intrinsically safe and associated apparatus must be handled with extra care. Any substandard intrusions may reduce or eliminate the intrinsic safety of the system. It is vital to understand the concepts of segregation, separation and clear identification of the components.

For intrinsically safe circuits, the correct installation procedures must be followed to ensure that the maximum value allowed for current and voltage cannot be exceeded because of external electric or magnetic fields. For example, proper installation requires cables to be used which are adequately shielded and separated from the cables of other circuits.

The connection elements, ie terminal block housing, protective enclosures for cables, external enclosures for single conductors, the wiring between intrinsically safe apparatus and associated apparatus, must be clearly marked and easily identified.

The identification of the apparatus and the requirements necessary to maintain the intrinsic safety of the system, or the essential elements of the design documents containing these requirements, must be clearly and permanently marked on the required label.

No method of protection is completely safe or protected from human error. Proper maintenance is required and includes rigorous initial inspection and verification. Subsequent planned maintenance, periodic inspection and repair are extremely important for the safety management of any instrumentation plant.

19.5 Testing Electrical Equipment in Hazardous Areas

All electrical apparatus and associated circuitry must be tested in accordance with a defined testing procedure and the results recorded.

Testing and maintaining intrinsically safe equipment should be carried out by qualified personnel only and who are familiar with the particular techniques involved. All work must be carried out in accordance with onboard safety risk assessment and permit to work requirements.

Approvals			
Country (Authority)	**Certificate File No.**	**Standard**	**Approved for**
Australia (SA)	AUS Ex1288 X	AS 2380.7-1987	(Ex ia) IIC / IIB
Canada (CSA)	LR 66259-7	C22.2 No.157	Cl.I, II, III; Div 1; Gr.A to G
Europe (CESI)	EX-90.C.117X	EN 50.020 EN 50.014	(EEx ia) IIC / IIB
USA (FM)	J.I. 3T3A3.AX	FM Cl. No.3610 Entity FM Cl. No. 3611 Non Incend	Cl.I, II, III; Div.1; Gr.A to G Cl.I; Div.2; Gr.A to D

Table 19.1 – International IS approvals

20 Programmable Logic Controllers (PLCs)

20.1 Introduction

The first programmable logic controllers (PLCs) were introduced by the GM Corporation in 1968 to carry out the sequential operations that were previously achieved with relay logic. This was the first step towards control automation by providing a suitable replacement for the relays.

Programmable controller-based marine automation applications have gone through rigorous scrutiny proving their quality and safety in the marine environment and today offer more applications than were originally anticipated. They are able to communicate with other control systems, providing reports, diagnosing their own failures and those of the controlled process. Despite programmable controllers becoming more sophisticated, they still retain the simplicity and ease of operation that was intended in their original design.

Today, every aspect of the marine industry uses PLCs and they are used in a variety of applications, including propulsion systems, safety systems, data acquisition and motor starters. They are reliable and require relatively little maintenance.

20.2 PLC Basics

PLCs, also called programmable controllers, are solid-state devices which use integrated circuits instead of electromechanical ways to control functions. They can store instructions, including sequencing, timing, counting, arithmetic, data manipulation and communication to control processes.

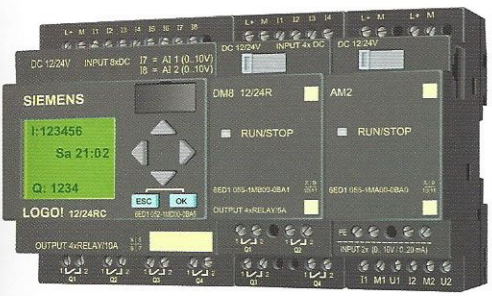


Figure 20.1 – Siemens LOGO PLC

The most essential PLC components shown in Figure 20.1 are:

- Power Supply Module – can be built into a PLC or a separate unit
- Processor Module or CPU – operates the process by input/output (I/O) modules
- Memory Modules – often involve an internal buffer battery to secure data storage in case of main power loss
- Input Module – responsible for acquiring data from measuring points and a variety of controls
- Output Module – responsible for sending respective output signals to actuators
- Process Monitoring LEDs – integrated in PLC modules. They indicate the status of the inputs and outputs of the PLC including power on, program running and any faults. (In Siemens LOGO PLC shown in Figure 20.1 Inputs/Outputs indication is performed from screen).

The main purpose of the input/output interface is to condition the various signals received or sent by the PLC. Incoming signals from sensors, eg push buttons, limit switches, analogue sensors or selector switches, are hard-wired to terminals on the input interface. Devices that will be controlled (relays, motor starters, actuators, solenoid valves, pilot lights and position valves) are connected to the terminals of the output interface.

The power supply plays a major role in fault free PLC operation, it must be stable and reliable. Fluctuations up to 15% of line voltage should not affect PLC operation. If fluctuations cannot be prevented, constant voltage transformers and/or DC-DC isolated voltage converters are often installed to secure the required voltage. These types of power supply equipment use line filters to remove high-harmonic content and provide a clean sinusoidal output for the PLC.

The operation of a programmable controller is relatively simple (Figure 20.2).

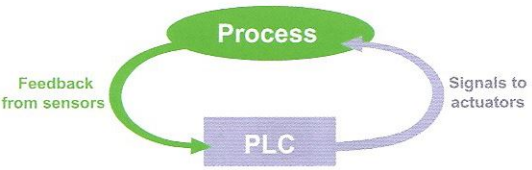


Figure 20.2 – PLC-based conceptual application diagram

The input/output (I/O) system is physically connected to devices in machinery or those which are used in controlling a process. These devices may be digital or analogue input/output devices, such as limit switches, pressure transducers, push buttons, motor starters, solenoids and relays. The I/O interfaces provide a connection between the CPU, the information providers (inputs) and the controllable devices (outputs). During CPU operation three processes are completed:

- Input data is received from the devices via the input interface
- executing the control program stored in the memory system
- updating (writing) the output devices via the output interfaces.

Actuators drive the system, activating changes of state or operation modes. The control loop operates on a continuous cycle interpreting the PLC inputs, solving the preset program algorithm and then changing the outputs. As with any computation device this does not happen instantly. Figure 20.3 shows the basic operation cycle of a PLC.

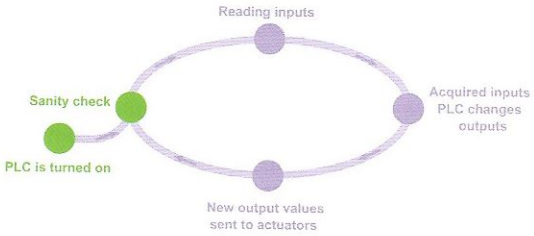


Figure 20.3 – PLC operation cycle

When power is applied to the PLC, a sanity check is made to ensure that the hardware is functioning properly. The PLC will stop indicating any errors it has detected (eg if the PLC backup battery is weak and the power supply lost, the memory will be corrupt resulting in a fault).

After the sanity check, the PLC will read and store the inputs in the operation memory. The algorithm will be scanned using the preset stored values, not the current values. This prevents logic problems when inputs change during the scan. Once complete, the outputs will be scanned and the output values will change. The system will repeat the sanity check and the loop continues indefinitely with every scan. The typical time required for each of the stages is in the order of milliseconds.

20.2.1 PLC Terminology

The language of PLCs consists of a commonly used set of terms, many of which are unique to PLCs. In order to understand the ideas and concepts of PLCs, it is necessary to understand these terms. Figure 20.4 is an example of a PLC-based Star-Delta motor starter.

A sensor is a device which converts a physical condition into an electrical signal for use by the PLC. Sensors are connected to the input of a PLC. A pushbutton is an example of a sensor that is connected to the PLC input. An electrical signal is sent from the pushbutton to the PLC indicating the condition (open/closed) of the pushbutton contacts.

A discrete input (also referred to as a digital input or binary input) is an input which is either in an on or off condition. Pushbuttons, toggle switches, limit switches, proximity switches, circuit-breaker auxiliary contacts are all examples of discrete sensors which are connected to the PLC's inputs. In the on condition a discrete input may be referred to as 'logic 1' or 'logic high'. In the off condition a discrete input may be referred to as 'logic 0' or a 'logic low'.

An analogue input is a continuous, variable signal. Typical analogue inputs may vary from 0 to 20 milliamps, 4 to 20 milliamps or 0 to 10 volts.

A discrete output is an output which is either in an on or off condition. Solenoids, contactor and relay coils are examples of actuator devices connected to discrete outputs. Discrete outputs may also be referred to as digital outputs. Figure 20.4 illustrates that a motor can be turned on or off by the PLC outputs.

Actuators convert an electrical signal from the PLC into a physical condition. Actuators are connected to the PLC output. In this case, the contactors are actuators for the motor.

The Central Processor Unit (CPU) is a microprocessor system which contains the system memory and is the PLC decision making unit. The CPU monitors the inputs and makes decisions based on instructions held in the program's memory. The CPU performs relay, counting, timing, data comparison and sequential operations.

A program consists of one or more instructions that will accomplish a task. Programming a PLC is simply

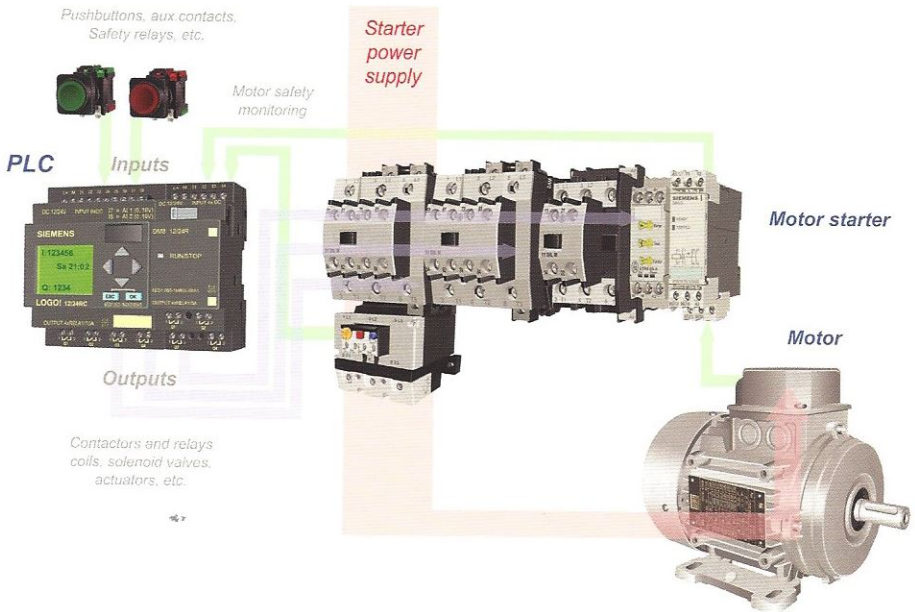


Figure 20.4 – PLC-based Star-Delta motor starter architecture

constructing a set of instructions. There are several ways to look at a program such as ladder logic, statement lists or function block diagrams.

Ladder Logic (LAD) is a programming language used with PLCs. Ladder logic uses components that resemble elements used in a line diagram format to describe hard-wired control.

Random Access Memory (RAM) is where data can be directly accessed at any address. Data can be written to and read from RAM. RAM is used as a temporary storage area.

Any data which is stored in RAM will be lost if power is lost. A battery backup is required to avoid losing data if there is a power loss. Battery-supported RAM has proven to be sufficient for most programmable controller applications.

Read Only Memory (ROM) data can be read from this type of memory but not written to. This type of memory is used to protect data or programs from accidental erasure. ROM is non-volatile, this means a user program will not lose data if electrical power is lost. ROM is normally used to store the programs that define the capabilities of the PLC. The manufacturer normally creates ROM-based PLC programs at the factory. Once the manufacturer programs the original set of instructions, the user can never alter it.

Programmable Read Only Memory (PROM) is a special type of ROM which can be programmed. Very few programmable controllers today use PROM for application memory. When it is used, this type of memory is likely to be a permanent storage backup for some type of RAM. Once programmed, it cannot be easily erased or altered. Any program change requires a new set of PROM chips.

Erasable Programmable Read Only Memory (EPROM) provides some security against unauthorised or unwanted changes in a program. EPROMs are designed so that the stored data can be read, but not easily altered. UVEPROM (ultraviolet erasable programmable read only memory) can only be erased with an ultraviolet light. EEPROM (electronically erasable programmable read only memory) can only be erased electronically.

Electrically Alterable Read Only Memory (EAROM) is similar to EPROM, but instead of requiring an ultraviolet light source to erase it, the chip can be wiped clean by an erasing voltage on the proper pin of the EAROM.

Firmware is user or application specific software burned into EPROM and delivered as part of the hardware. Firmware gives the PLC basic functionality.

20.3 Source-Sink Inputs

PLC inputs are isolated by photo-couplers to prevent errors due to contacts chattering (rapid cycling on and off), short- to-earth errors and other electrical noise that may occur.

When a PLC is connected for 'source-inputs', the input current flows in, as illustrated in Figure 20.5.

Here the current registered by a PLC must not be less than 4 mA or the PLC will not register. This means the input status would remain false. The current must not exceed 8 mA or it could result in damage.

When the PLC is connected for 'sink-inputs' the current will flow as illustrated in Figure 20.6.

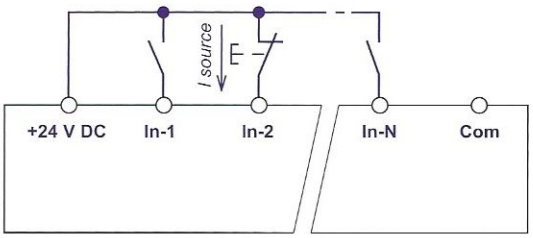


Figure 20.5 – Sourcing input

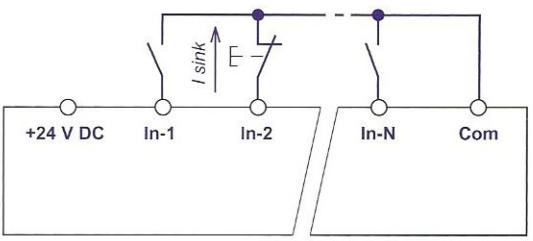


Figure 20.6 – Sinking input

20.4 Outputs

There are three types of PLC output:

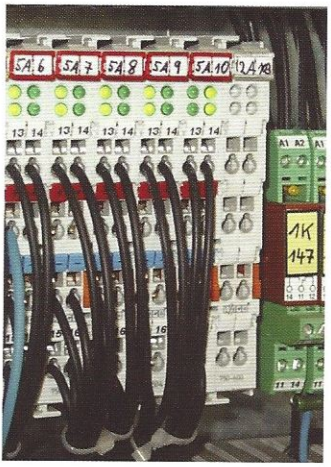
- **Relay**. This is the most commonly used type of output. The coils and contacts of the output relays allow electrical isolation between the output devices and internal PLC circuits. The maximum switched current for an individual relay output stays within 2 A
- **Triac** (Solid State Relay). The Triac is an AC switch, which consists of two thyristors connected back-to-back. As the Triac output is a solid state, it will last longer than a relay output. Due to a voltage range of 85-240 V AC, each output can switch up to 0.35 A of a load
- **Transistor**. Outputs which are used if a fast switching time is required.

20.5 Input/Output Extension Modules

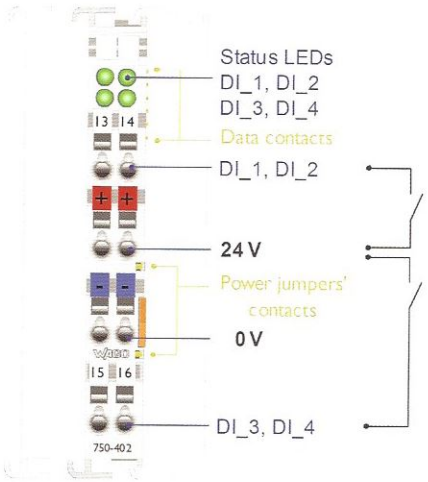
To extend the number of inputs and outputs connected through the PLC network, a standardised DIN module installation is employed by manufacturers for the following PLC-based applications:

- Digital Input Module (DI)
- Analogue Input Module for RTD (AI)
- Analogue Input Module for TCs
- Analogue Input Module for 4-20 mA
- Digital Output Module (DO)
- Analogue Output Module (AO) 0-10 V DC
- Analogue Output Module 0-20 mA.

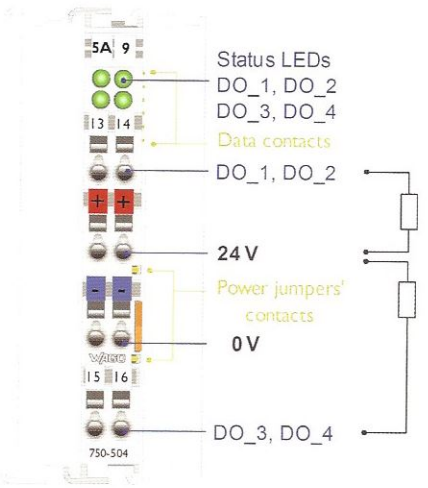
The WAGO 750 system Digital input and Digital output module wiring features are illustrated in Figure 20.7.



a)



b)



c)

Figure 20.7 – a) WAGO 750 I/O system
b) 4 x Digital Input module 750-402
c) 4 x Digital Output module 750-504

The Siemens LOGO PLC (Figure 20.8) has both digital (a) and analogue (b) extension modules. Digital input and output modules are available for operation using different voltages (12 V DC, 24 V AC/DC and 115-240 AC/DC) and incorporate four inputs and four outputs. Analogue modules are available for operation with 12 V DC or 24 V DC and are equipped with two analogue inputs (0-10 V/0-20 mA) or two Pt 100 inputs.

Figure 20.8 – Siemens LOGO extension modules

20.6 Ladder Logic

Ladder logic is the most conventional control language and has a recognisable plant standard, ie the ladder diagram format.

It is called a ladder diagram as the relay logic runs in parallel lines between two power lines and the whole diagram resembles a ladder. This diagram consists of a vertical line running down the left side with horizontal lines branching off to the right (Figure 20.9), where output is located.

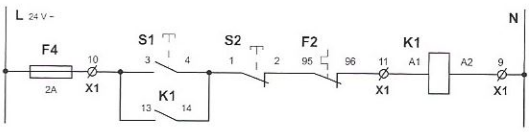


Figure 20.9 – DOL starter ladder diagram

Ladder diagrams are also called contacts' symbology, since the instructions are relay-equivalent contact symbols, ie normally open and normally closed contacts and coils. These diagrams represent the interconnection of devices, so that the activation or turning 'on' of one device will turn 'on' another device according to a predetermined sequence of events.

Ladder logic is a programming language that was developed from ladder diagrams. Therefore, it has much in common with relay logic. If the controller language is ladder logic, the translation from existing relay logic to programmed logic is a one-step translation.

Figure 20.10 illustrates the PLC transformation of the DOL starter ladder diagram shown in Figure 20.9, to a PLC format.

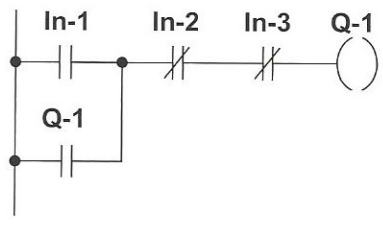


Figure 20.10 – PLC-based DOL starter ladder logic

The line on the left is the busbar and the horizontal lines are the instruction lines or rungs. One output

per rung is normal for most controllers. Conditions are placed along the instruction lines which lead to other instructions on the right side. Power flow is always from left to right. Therefore, the logical combination of these conditions from left to right determines when and how the instructions at the right side are executed. In a ladder logic diagram, instruction lines can have multiple branches. The vertical pairs of lines are called conditions. As previously mentioned, the CPU reads the status of inputs, energises the corresponding circuit element according to the program and controls a real output device via the output interface.

20.6.1 Basic Instructions

When considering a PLC-based motor starter, care should be taken with inputs, outputs and logic. The symbols illustrated below in Figures 20.11 to 20.14 are used to translate ladder diagrams (relay logic) into ladder logic. These symbols are also the basic instruction set for programming.

Figure 20.11 – Normally open input

Normally open input I (Figure 20.11) represents any input to the control logic. An input can be a connected switch closure or sensor, a contact from a connected output or a contact from an internal output. When interpreted, the referenced input or output is examined for an 'on' condition. If the status is 1, the contact will close and allow current to flow through the contact. If the status of the referenced input/output is 0, the contact will remain open, prohibiting any current from flowing through the contact.

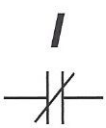


Figure 20.12 – Normally closed input

Normally closed input I (Figure 20.12) represents any input to the control logic. An input can be a connected switch closure or sensor, a contact from a connected output or a contact from an internal output. When interpreted, the referenced input/output is examined for an 'off' condition. If the status is 0, the contact will remain closed, allowing the current to flow through the contact. If the status of the referenced input/output is 1, the contact will open, prohibiting current from flowing through the contact.

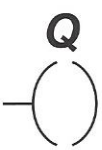


Figure 20.13 – Output Q

Output Q (Figure 20.13) represents any output that is driven by some combination of input logic. An output can be a connected device or an internal output. If any left-to-right path of input conditions is 'true' (all contacts closed), the referenced output is energised (turned 'on').

Figure 20.14 – NOT output Q

NOT output Q (Figure 20.14) represents any output that is driven by some combination of input logic. An output can be a connected device or an internal output. If any left-to-right path of input conditions is 'true' (all contacts closed), the referenced output is de-energised (turned 'off').

The following seven points outline the guidelines for the translation of hard-wired logic to programmed logic using PLC contact symbols:

- **Normally open contact**. When evaluated by the program, this symbol is examined for a 1 to close the contact. Therefore, the signal referenced by the symbol must be 'on', 'closed', 'activated', etc
- **Normally closed contact**. When evaluated by the program, this symbol is examined for a 0 to keep the contact closed, the signal referenced by the symbol must be 'off', 'open', 'de-activated', etc
- **Output**. An output on a given rung will be energised if any left-to-right path has all its contacts closed, with the exception of the power flow going in reverse before continuing to the right. An output can control either a connected device (if the reference address is also a termination point) or an internal output used exclusively within the program. An internal output does not control a field device. It provides interlocking functions within the PLC instead
- **Input**. This contact symbol can represent input signals sent from connected inputs, contacts from internal outputs or contacts from connected outputs
- **Contact addresses**. Each program symbol is referenced by an address. If the symbol references a connected input/output device, then the address is determined by the point where the device is connected
- **Repeated use of contacts**. A given input, output or internal output can be used throughout the program as often as required
- **Logic format**. Contacts can be programmed in series or in parallel, depending on the output control logic required. The number of series contacts or parallel branches allowed in a rung will depend on the PLC.

20.6.2 Logic Functions

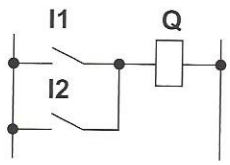
To understand programmable controllers and their applications, the logic concepts behind them must be understood.

The binary concept refers to the idea that many things exist in two pre-determined states ON or OFF. For example, a toggle switch contact can either be open or closed, motor starters can be turned on or

off. In digital systems these two-state conditions can be thought of as signals present or not present, activated or not activated, true or false, high or low. This concept is a fundamental to PLCs.

In this case, binary 1 represents the presence of a signal, while binary 0 represents the absence of a signal. Operations performed by PLCs are based on three fundamental logic functions OR, AND and NOT. These functions combine binary variables to form statements. Each function has a rule that determines the statement outcome (TRUE or FALSE) and a symbol that represents it.

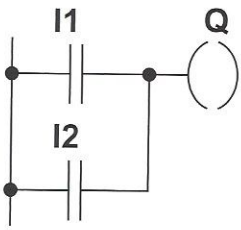
If using a standard binary notation for the condition of the contacts I1 and I2 as inputs and relay coil Q as an output, a Truth Table shows how the different ladder logic functions work.



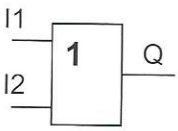
a)

I1	I2	Q
0	0	0
0	1	1
1	0	1
1	1	1

b)



c)

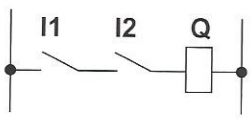


d)

Figure 20.15 – OR-logic function
a) Ladder diagram b) Truth table
c) Ladder logic d) OR-function block

Figure 20.15 illustrates that relay Q will become energised if contact I1, I2 or both contacts become closed when connected in parallel. The parallel contacts circuit represents OR-Logic Function.

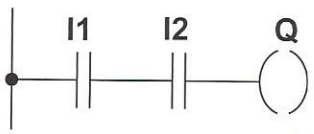
In Figure 20.16(a), relay Q will only become energised when both I1 and I2 close, either simultaneously or one after the other, when connected in series.



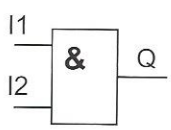
a)

I1	I2	Q
0	0	0
0	1	0
1	0	0
1	1	1

b)



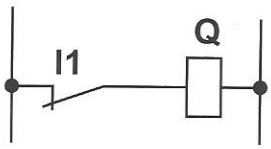
c)



d)

Figure 20.16 – AND-logic function
a) Ladder diagram b) Truth table
c) Ladder logic d) AND-function block

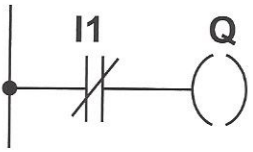
Contacts which are connected in series represent AND-Logic Function. The function block of an AND-logic gate is illustrated in Figure 20.16d.



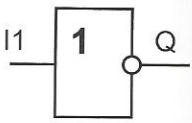
a)

I1	Q
0	1
1	0

b)



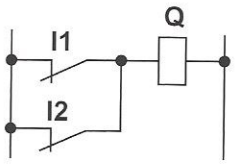
c)



d)

Figure 20.17 – NOT-logic function
a) Ladder diagram b) Truth table
c) Ladder logic d) Function block

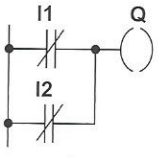
The circuitry, illustrated in Figure 20.17, represents NOT-logic function. The meaning is: if contact I1 remains closed, relay Q will be energised on applying the power supply. If contact I1 opens, relay Q is de-energised.



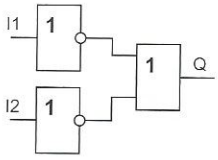
a)

I1	I2	Q
0	0	1
0	1	1
1	0	1
1	1	0

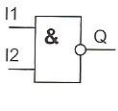
b)



c)



d)

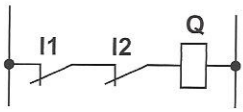


e)

Figure 20.18 – NAND logic function
a) Ladder diagram b) Truth table
c) Ladder logic d) and e) NAND-Function block

By inverting an OR-function's inputs using NC contacts instead of NO contacts (as in Figure 20.15a), a NAND function is created.

Relay Q will only be de-energised when both inputs, I1 and I2, are turned on. The converted NAND function symbol is shown in Figure 20.18 (d) and (e).



a)

I1	I2	Q
0	0	1
0	1	0
1	0	0
1	1	0

b)

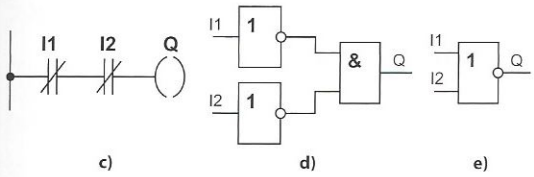
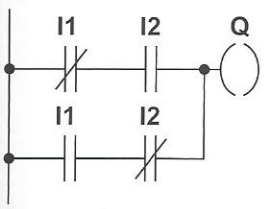


Figure 20.19 –NOR-function
a) Ladder diagram b) Truth table
c) Ladder logic d) and e) NOR-Function block

Similarly, if each input of an AND function (Figure 20.16) is inverted using NC contacts, a NOR-function is created (Figure 20.19).

In the truth table represented in Figure 20.19b, relay Q will remain energised if both inputs remain closed. NOR function block is illustrated in Figure 20.19(e).

The combination logic functions can be built up by grouping contacts in series-parallel arrangements. In the following example, an Exclusive-OR function is built from a combination of AND, OR and inverter (NOT) gates (Figure 20.20).



I1	I2	Q
0	0	0
0	1	1
1	0	1
1	1	0

b)

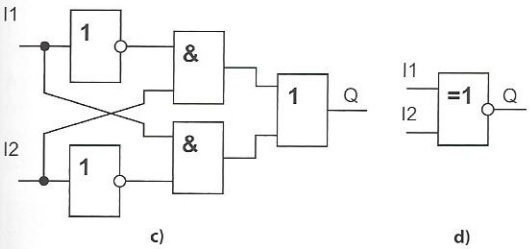


Figure 20.20 –Exclusive-OR function a) Ladder logic
b) Truth table c) and d) Function block

20.6.3 DOL Starter Ladder Logic

The logic implemented in PLCs is based on the three basic logic functions (AND, OR and NOT) that were discussed in the previous section. These functions are used either alone or in combination to form instructions which will determine if a device is to be switched on or off. How these instructions are implemented to send commands to the PLC is called the language. The most widely used languages for implementing on/off control and sequencing are ladder diagrams and Boolean mnemonics.

Taking a DOL starter diagram as an example, Figure 20.9, and employing the basic instructions which were explained in section 20.6.1, a DOL ladder logic diagram can be created (Figure 20.21). Begin by assigning PLC inputs and outputs for each of the ladder diagram elements.

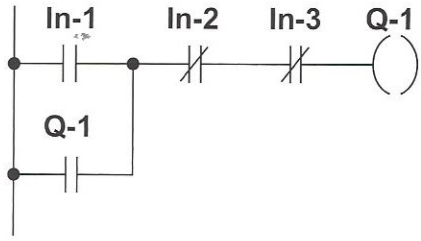


Figure 20.21 – DOL starter ladder logic

Our inputs are determined by In-1 – start button S1, In-2 – stop button S2, In-3 – NC contact of overload relay F2 and the output Q-1, which is associated with the coil of contactor K1.

Input and output conditions can be identified as '0' or '1'. Condition '0' means that the input does not carry voltage. Condition '1' means that the input carries voltage.

A DOL logic circuit operates when In-1 receives an input (associated with the start button S1) changing it to condition 1. In-2 and In-3 remain in the existing condition 1, ie contacts S2 and F2 remain closed. The PLC will initiate DOL logic, providing an output signal at Q1, starting the electric motor. Once started, the other internal input (instance of Q1) has its function set for input In-1 keeping the electric motor running irrespective of input if the operator releases the start button S1.

Using Ladder Logic language (also known as LAD) for PLC programming does not require any additional specific knowledge, but some experience with ladder diagrams is necessary. A PLC can be programmed via an inbuilt interface by using the panel screen and pushbuttons or PC based interface. The following example illustrates programming by using the 'Siemens LOGO! SOFT COMFORT v.5.0' system. The logic circuit derived in Figure 20.19 should be transferred to a PC, where the software is installed (Figure 20.22).

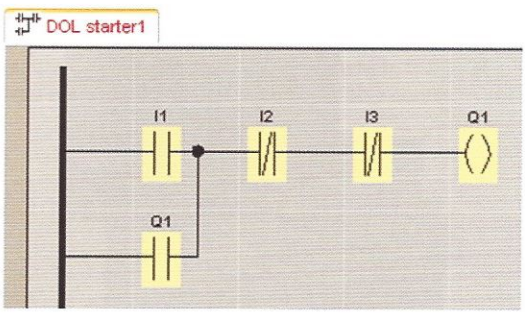


Figure 20.22 – DOL logic circuit viewed via the *LOGO! SOFT* interface

By using the software, the ladder diagram (LAD) can be presented in function blocks (FBD) as illustrated in Figure 20.23.

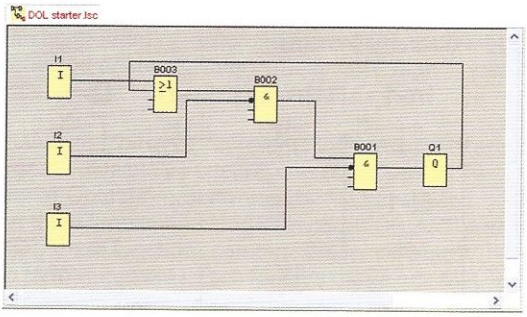


Figure 20.23 – Function blocks diagram for DOL starter logic

Simulating this diagram we can ensure that the logic circuit will work once the PLC is programmed.

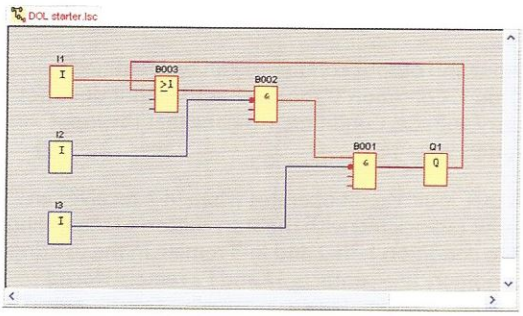


Figure 20.24 – DOL starter logic circuits simulation (Input *I1* is active)

The wiring features for a DOL PLC-based motor starter are shown in Figure 20.25.

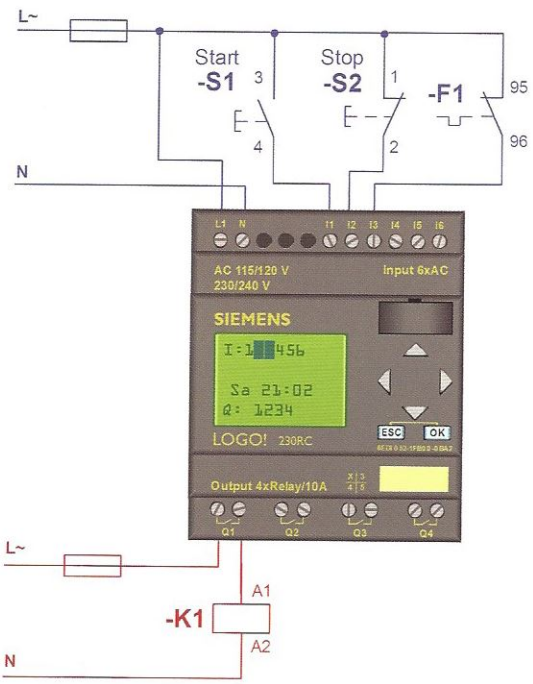


Figure 20.25 – PLC-based DOL starter wiring to a PLC showing a typical connection between input and output

In Figure 20.25 it appears that the wiring does not correspond with the example of a DOL diagram. In reality, the logic diagram is rarely detailed in line diagrams. However, engineers should be familiar with the ship's automation devices through routine maintenance and have little difficulty troubleshooting PLC-based applications.

20.7 Troubleshooting PLC-Controlled Circuits

From the beginning, programmable controllers have been designed with ease of maintenance in mind. With virtually all components being solid-state, maintenance is reduced to replacing modular, plug-in components. Fault detection circuits and diagnostic LED indicators are incorporated in each major component, signalling whether the component is working correctly or has malfunctioned.

What would help in troubleshooting a PLC-based application is if an application's working algorithm is clearly understood. As previously mentioned, an understanding can be gained from interpreting a ladder diagram.

20.7.1 Power Supply

A CPU power supply plays a major role in fault free PLC operation, it must be stable and reliable. Therefore, before troubleshooting the power supply should be checked. Further PLC troubleshooting assumes that the power supply is not overloaded or shorted to earth, but is maintained within the acceptable limits.

Where memory backup batteries are used for certain PLCs (Figure 20.26), care should be exercised to replace the batteries so that essential data is not lost if there is a power break.

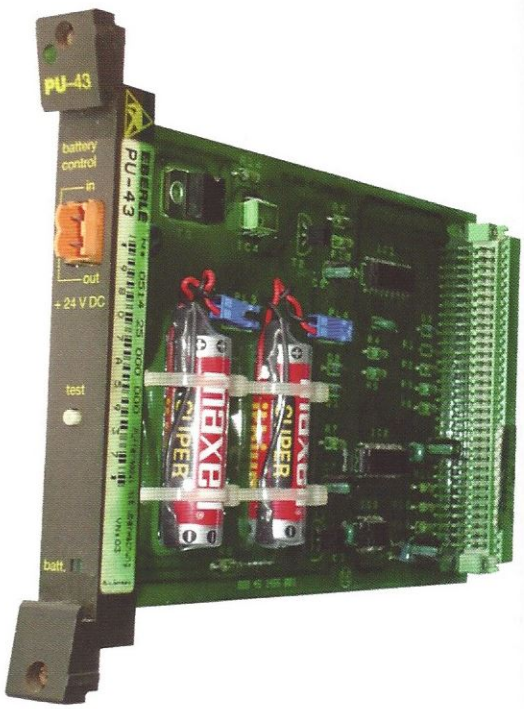


Figure 20.26 – EBERLE PLS-514 buffer module equipped with Li-batteries

Battery life depends on many factors (burden circuit current consumption, number of breakdowns in the main power supply, etc).

The battery replacement procedure involves a specific sequence of actions set by the manufacturer. Before replacing a battery you should be familiar with these procedures.

20.7.2 Verifying Input Condition

Most malfunctions associated with PLC-based systems occur from failures directly related to the field input/output devices (Figure 20.27).

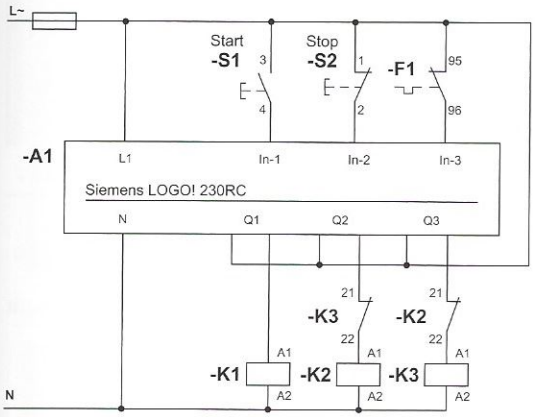


Figure 20.27 – Field devices connected to LOGO! I/O terminals

Taking this into account, circuit troubleshooting should start by verifying the input condition in respect to logic interpreted from the circuit diagram (Figure 20.27):

- In-1 should have no input signal unless the starting order is given (ie S1/3-4 being closed by the operator)
- In-2 should be present because –S2 contact 1-2 is normally closed
- In-3 should be present because –F1 contact 95-96 is normally closed.

As LOGO! PLC continuously monitors field devices, reflecting their condition via the operator's interface display (Figure 20.28), the information received should be useful while troubleshooting.

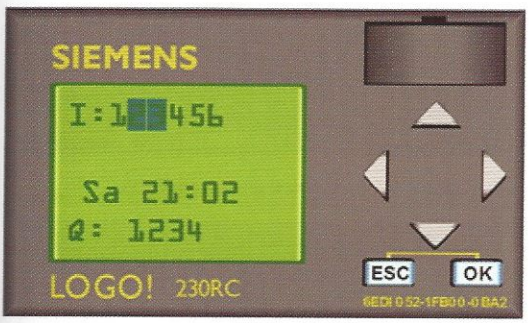


Figure 20.28 – LOGO! operator's display. Inputs I:2, I:3 (highlighted with blocks) are active

If no imbalanced inputs are indicated, continue troubleshooting by checking the outputs.

Checking inputs should be not be an issue unless PLCs are encountered where the I/O network consists of a higher number of inputs (32-, 64-, etc) as illustrated in Figure 20.29. It would take a long time to check each input without advanced troubleshooting logic.

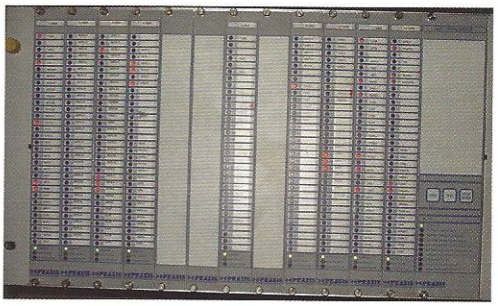


Figure 20.29 – Wärtsilä L38 engine's PRAXIS PLC overview at I/O modules

20.7.3 Verifying Output Condition

In the example outputs Q1 and Q2 conditions will become -1- once pushbutton S1 is pressed and the outputs should be checked once the In-1 condition becomes -1-.

If the output is displayed as active via the interface display (Figure 20.30), but the output field devices are not being energised (K1 and K2 coils remain de-energised), a problem can be anticipated with the PLC discrete output relays*.

Note: it is assumed that K1-K3 coils are not burnt;

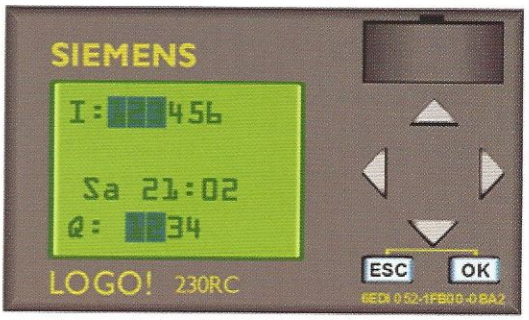


Figure 20.30 – LOGO! operator's display. Inputs I:1, I:2, I:3 and outputs Q:1, Q:2 (highlighted) are active

If no output is given and all inputs correspond to the CPU run condition (In-1 condition is 1, In-2 condition is 1 and In-3 condition is 1), it indicates that there is a CPU malfunction. Figure 20.31 shows a digital output controller's relay contacts, where the fault may have been caused by a worn relay contact.

Figure 20.31 – Siemens LOGO! PLC output relays

After checking the input and output networks and ensuring that neither the input nor the output circuits have failed, and where output is not given even after input In-1 became -1- (S1 pushbutton contact is closed), it is likely there has been a CPU-related malfunction.

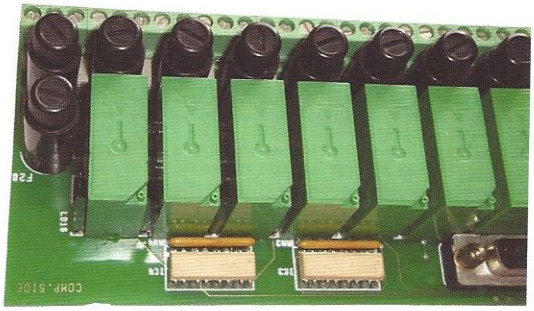


Figure 20.32 – Wärtsilä L38 engines PLC-based local control system discrete output termination board incorporates 16 output relays, the condition of which are monitored by LEDs adjacent to each relay

20.7.4 CPU Diagnostics

Additional controller feature functions make locating errors easier. Errors can be divided into two categories according to severity:

- Fatal errors are severe and prevent the PLC from operating until their cause is located and resolved
- Non-fatal errors are those that do not prevent the PLC from operating. After detecting one or more non-fatal errors, program execution will continue. Nevertheless, it is necessary to correct these errors as soon as possible.

The CPU is responsible for detecting communication and other failures that may occur during system operation. It must alert the operator or system if there is a malfunction. To do this, the processor performs diagnostics or error checks during operation and sends status information to indicators which are normally located on the front of the CPU. As the CPU incorporates a power and a memory module, typical diagnostics include a power supply check, processor check, memory check and backup battery check. Such errors, if they occur, are indicated by using corresponding LEDs, which are located in front of the CPU module (Figure 20.33, Figure 20.34).

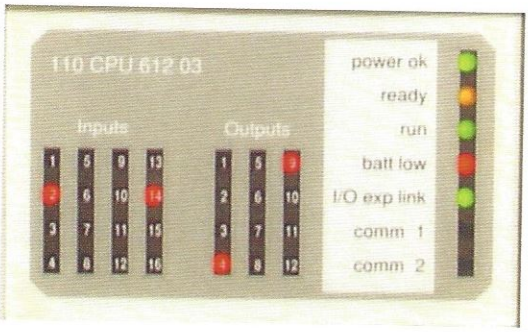


Figure 20.33 – AEG modicon CPU 612 error monitoring interface

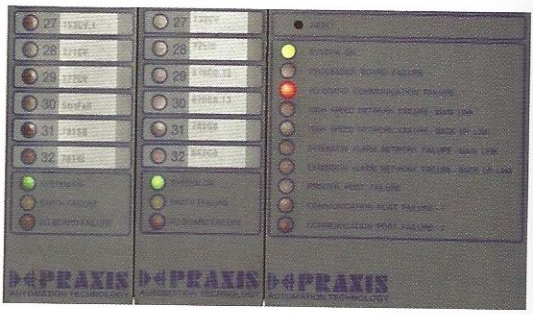


Figure 20.34 – Praxis PLC. 6001 CPU error monitoring interface

Some controllers have a set of fault relay contacts which can be used through an external alarm circuit to signal a failure. The processor controls the fault relay and activates it when one or more specific fault conditions occur.

When it is confirmed that the CPU has malfunctioned, the rebooting procedure should be carried out for recovery. Different PLC manufacturers describe how to carry out rebooting or CPU downloading procedures, it is not always carried out by resetting a PLC's power supply. Therefore, it is essential that the manuals are read before trying to solve PLC-based malfunctions.

20.7.5 Stepping Forward to PLCs Troubleshooting

The images in Figures 20.35 to 20.38 represent PLCs from various ship installations.

Figure 20.35 – KaMeWa control pitch propeller PLC

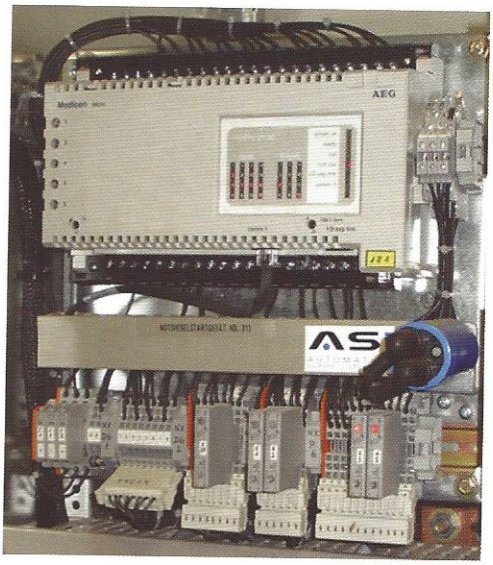


Figure 20.36 – SAM Electronics generator PLC

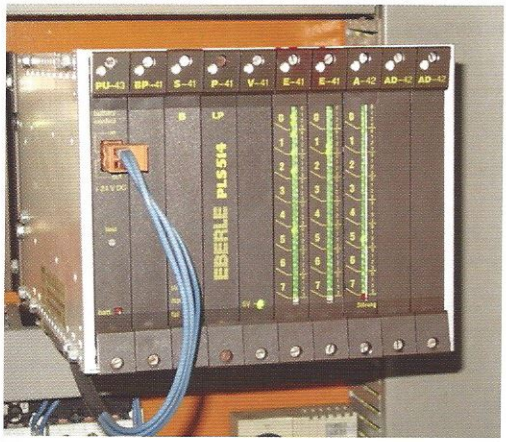


Figure 20.37 – LMG cranes PLC

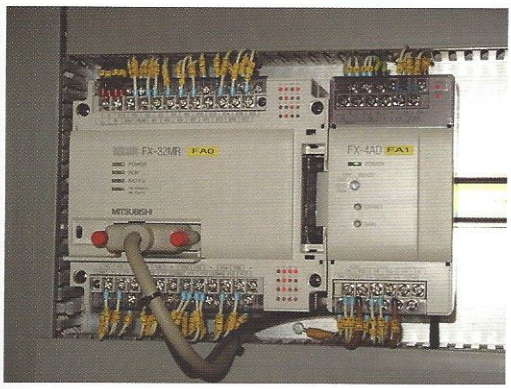


Figure 20.38 – FRAMO anti-heeling PLC

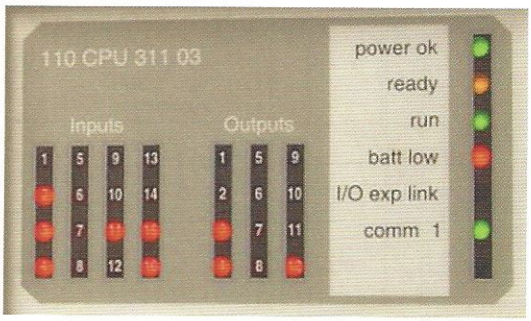
As the control programs that these PLCs execute vary, it is not possible to provide solutions for every specific malfunction, but we can provide troubleshooting tips and guidelines for understanding the problem-solving process.

As most CPUs monitor their input/output condition using LEDs, an I/O-status list for trouble shooting PLCs is required. It is helpful to write I/O statuses for the PLC modes. When a couple of PLCs are used in a network, I/O status should be written down for each PLC.

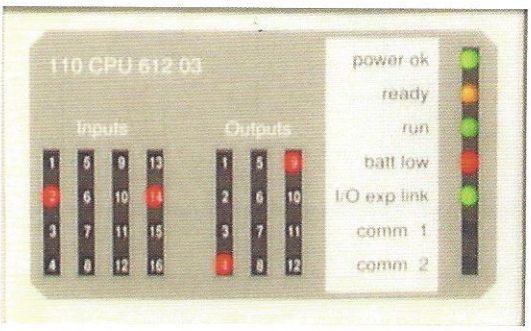
A SAM Electronics PLC-based generator panel is illustrated in Figure 20.39.

Figure 20.39 – SAM Electronics power plant generator panel overview

The manufacturer employs an AEG Modicon 110 CPU 311 as the diesel engine's controller (left hand side of Figure 20.39) and an AEG Modicon 110 CPU 612 as the generator's controller (seen on the right hand side). These are connected in a common network. Both CPUs have different modes of operation (stand-by mode, running idle with nominal rpm and circuit-breaker closed/generator under load sharing power in parallel). As illustrated in Figure 20.40, the status of the CPU's individual inputs and outputs are monitored with LEDs. When documenting the I/O status, we note the LEDs status.



a)



b)

Figure 20.40 – SAM Electronics power plant generator's panel I/O interface monitoring

The I/O status would therefore appear as:

DG is in stand-by mode:

-1A1 110 CPU 311 Inputs: 2; 3; 4; 11; 15; 16;
Outputs: 3; 4; 12;
-1A1 110 CPU 311 Inputs: 2; 3; 4; 5; 9; 13; 15; 16
Outputs: 4,9

DG runs under load:

-1A1 110 CPU 612 Inputs: 2; 3; 4; 5; 9; 13; 15; 16
Outputs: 4; 5; 6; 12
-1A1 110 CPU 612 Inputs: 2; 4; 7; 14 Outputs: 1; 2; 4; 5; 9

Any imbalance registered between the two statuses should be interpreted as an imbalance in either inputs or outputs. Use the PLC's connection diagrams to determine whether it is a faulty input or output.

Figures 20.41 to 20.44 represent part of the input/output circuits for various PLC-based systems.

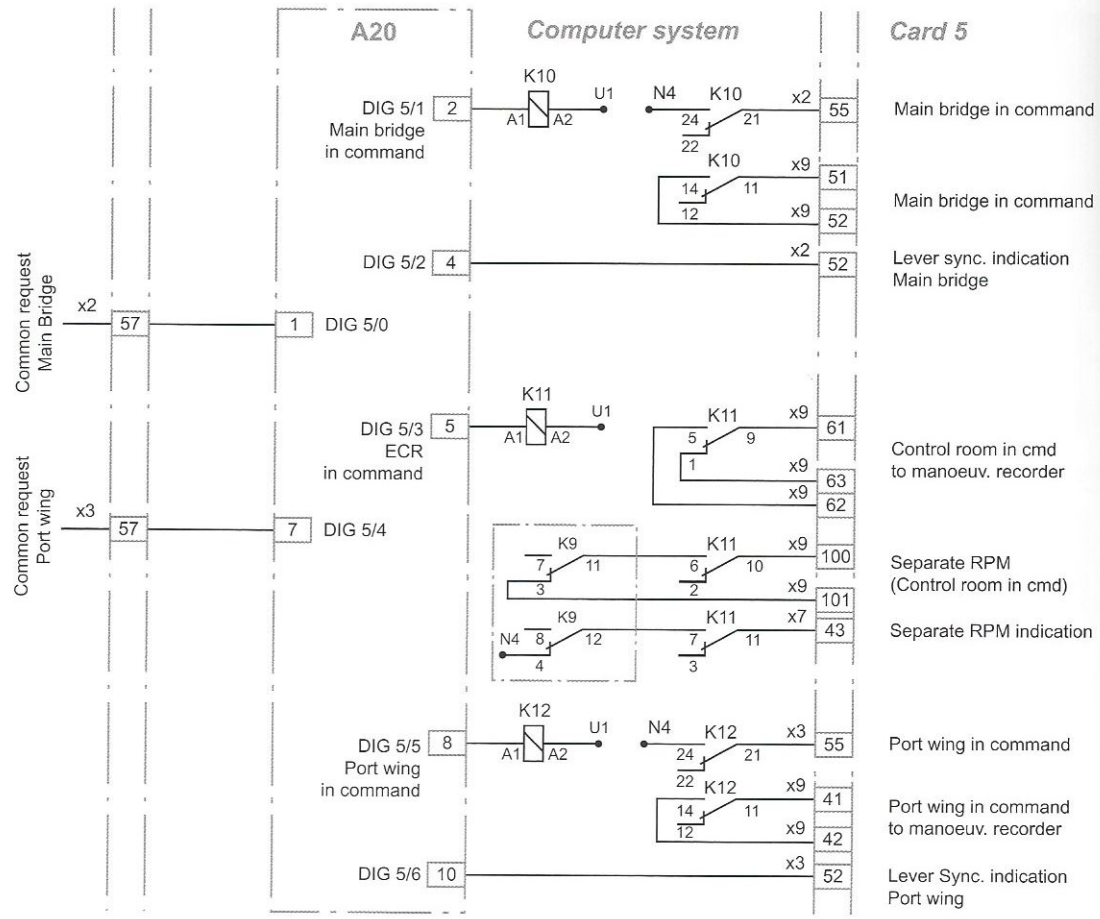
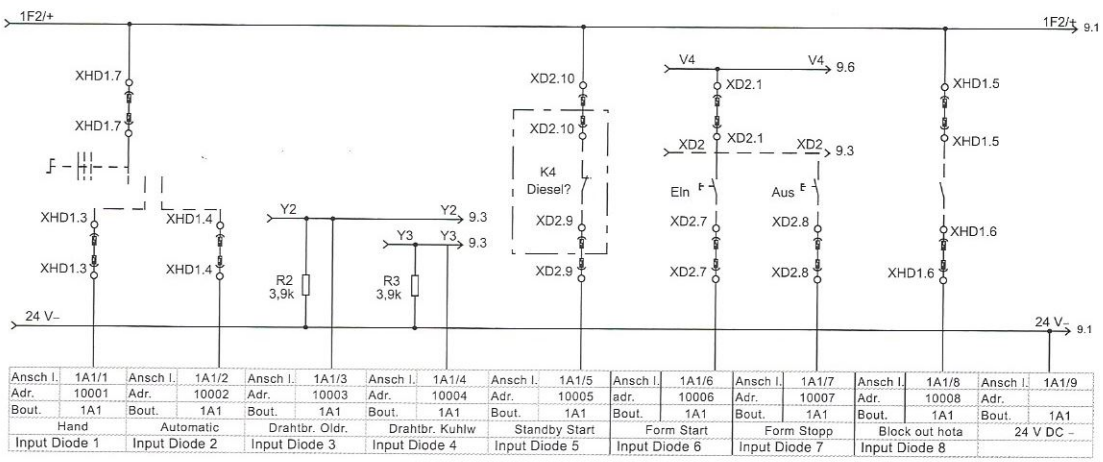


Figure 20.41 – KaMeWa propulsion PLC (extraction from original diagrams)



AEG Modicon Micro CPU 311-03

Figure 20.42 – SAM Electronics MSB generator's PLC (extraction from original diagrams)

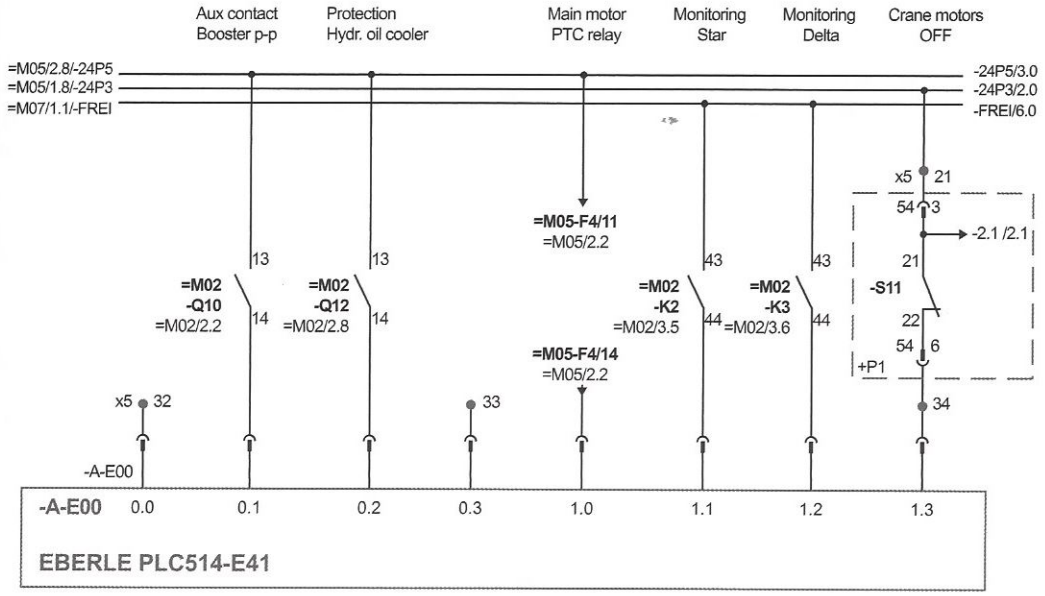


Figure 20.43 – LMG-KRUPP crane PLC (extraction from original diagrams)

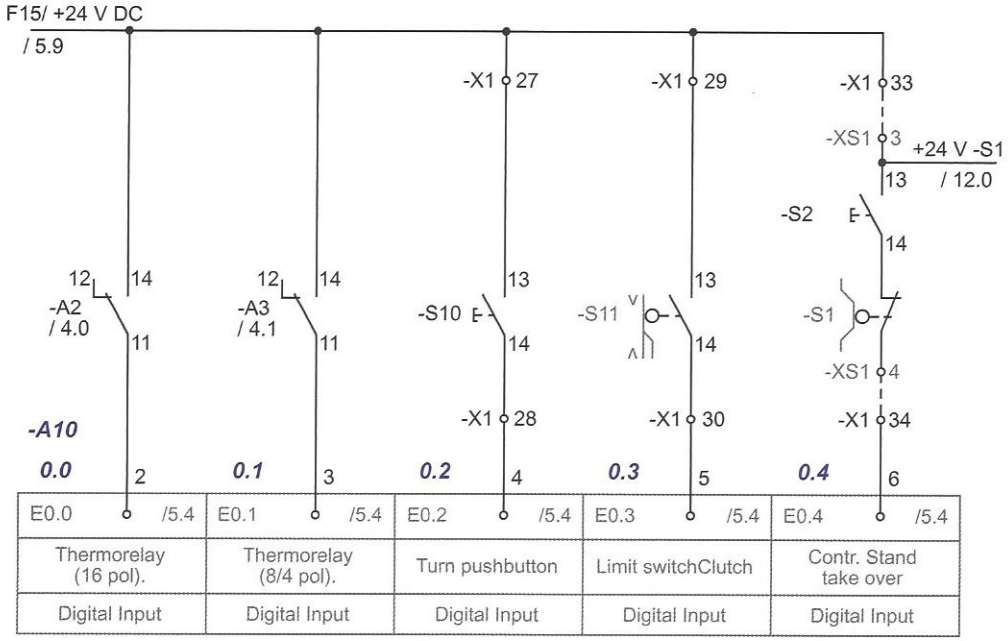


Figure 20.44 – HATLAPA anchor winch Siemens Simatic S7 PLC (extraction from original diagrams)

Additional information is often required to read the status of in/out LEDs from the PLC.

The latest generation of PLCs are equipped with operator interfaces (Figures 20.45 and 20.46) where the condition of inputs, outputs and even the values of analogue I/O signals can be viewed on the operator's display, but no manufacturer has removed discrete I/O LED monitoring as an additional source of information.

Figure 20.45 – TTS-LMG 250 t crane operator's interface module

Figure 20.46 – GEA Westfalia Separator operator's interface module

20.8 Troubleshooting

By following the steps below, the source of the error and a solution may be obtained:

1. Check the PLC power supply, ensuring it is on and no alarms have been triggered.
2. Carefully check that all the fuses in the PLC appliance are functioning and that there are no loose wires or contaminated terminals in or around the installation.
3. Ensure that there is no external source of damage creating exposure to the marine environment (ie humidity, over heating, etc).
4. Check the CPU interface for alarms.
5. Ensure that the I/O status change corresponds to the input signals given by the operator (digital inputs, start-stop buttons, pressure and level switch signals, analogue input and process monitoring sensor signals). Compare the PLC I/O current and the I/O function chart to find the point of error.
6. If the inputs and outputs are okay, test the additional auxiliary relays attached to the PLC output circuitry, ie whether they are energised or de-energised.
7. If the fault remains, follow the manufacturer's instructions to reboot the PLC system.
8. After rebooting the PLC, ensure that the logic begins automatically, avoiding any problems achieving the run-condition.
9. If there is a logic backup (software or memory), try solving the problem by downloading the backup (re-installing the software).

21 Process Calibrators

21.1 Process Calibrators

A calibrator is considered as a handy tool for the calibration and troubleshooting of process control equipment.

Figure 21.1 – Calibrators

As explained in Chapter 18, mA, mV and frequency signals are used in a variety of electronic appliances including PLCs. Input signals are often required for calibrating and simulating processes during troubleshooting, so a Multifunction Process Calibrator is a useful instrument. A Multifunction Process Calibrator with a dual function display (calibrator and/or multimeter) is capable of the following functions:

- Constant voltage output: 0-1.5 V DC with a resolution of 0.1 mV, 0-15 V DC with a resolution of 1 mV
- constant current output: 0-25 mA with a resolution of 1 mA
- square wave output: 0.5 Hz-5kHz with an amplitude of 5 V, +/-5 V, 12 V and +/-12 V.

The resolution is the ability of the instrument to differentiate between two signals of close frequency. It is determined by the gate time.

The following processes can be managed using a Multifunction Process Calibrator:

- Two-wire transducer simulation on current loop
- two-wire transmitter operational checks
- R/I and U/I converters - transmitter simulation and operational checks
- thermocouple output simulation and operational checks
- frequency transmitter simulation and operational checks
- F/I converters - operational checks and simulation
- proximity transducers - operational checks and simulation.

At the end of this chapter, Table 21.1 gives a brief overview of the different process calibrators available from various manufacturers.

Manufacturer						
Model	**Altek**	**Escort**	**Fluke**	**Fluke**	**Beta**	**Transcat**
	820	2020	725	741B	MasterCal 990	Ez-Doc
mA Source	0-24 mA	0-24 mA	0-24 mA	0-22 mA	0-22 mA	0-24 mA
mA Measure	0-24 mA	0-24 mA	0-24 mA	0-110 mA	0-110 mA	0-24 mA
DC Volts Source	0-10.25 V	0-1,5; 0-15 V	0-10 V	0-15 V	0-15 V	0-20 V
DC Volts Measure	0-200 V	0-600 V	0-30 V	0-300 V	0-300 V	0-20 V
AC Volts Measure	0-250 V rms	0-300 V rms		0-300 V rms	0-300 V rms	
T/C Types	JKTE	JKTERSBLU NC	JKTERSBL UN	JKTERSBL UNC BP XK	JKTERSBL UNC	JKTERSBL UNC BP XK
RTD Types	Pt 100	Pt 100	Ni120, Pt 100, Pt 200, Pt 500, Pt 1000	Cu10, Ni120, Pt 100, Pt 200, Pt 500, Pt 1000	Cu10, Ni120, Pt 100, Pt 200, Pt 500, Pt 1000	Cu10, Cu50, Cu100, Ni120, Pt 100, Pt 200, Pt 500, Pt 1000, Pt 385-10, Pt 385-50
Ohms Range (Source & Measure)	0-400 Ohms source, 0-1000 Ohms measure	0-40 Mohms measure	0-3200 Ohms source	0-11,000 Ohms source	0-11,000 Ohms source	0-4,000 Ohms source
Freq Range (Source & Measure)	0-15,000 Hz	0,5 -4,800 Hz	1-10,000 Hz	0-50,000 Hz	0-50,000 Hz	0-10,000 Hz
Freq Source Output	fixed -1 V to 5 V square wave	fixed 5 V, 12 V square wave	fixed 5 V p-p square wave	variable 0.1 - 10 V p-p square wave	variable 0.1 - 10 V p-p square wave	variable 1-20 V p-p square wave
Dual Display		Yes	Yes	Yes	Yes	Yes
Continuity beeper	Yes	Yes				
Loop Supply		Yes	Yes	Yes	Yes	Yes
Documenting					Yes	Yes
Power	AA	NiMH (AA) pack & charger	AA	AA	NiMH pack & charger	AA

Table 21.1 – Multifunction calibrators' selection guide

22 Digital Multimeters

22.1 Introduction

Digital multimeters (DMM) are used for troubleshooting electrical circuits and systems and to perform various tests to measure different electrical quantities such as voltage, amperage, impedance and frequencies. Although DMM features and operations may vary, most abbreviations, symbols and terminology are standardised for convenience.

DMMs commonly use standard abbreviations to represent a quantity or term for quick recognition, as illustrated in Table 22.1.

AC	Alternating current or voltage
DC	Direct current or voltage
V	Volts
mV	Millivolts
kV	Kilovolts
A	Amperes
mA	Milliamperes
µA	Microamperes
W	Watts
kΩ	Kilohms
MΩ	Megohms
Hz	Hertz
kHz	Kilohertz
µF	Microfarads
nF	Nanofarads
°F	Degrees Fahrenheit
°C	Degrees Celsius
LOG	Readings are being recorded
Lo	Low
nS	Nanosiemens
MEM	Memory
MS	Time display in minutes: seconds
HM	Time display in hours: minutes
RPM	Revolution per minute
COM	Common
OL	Overload
T	Time
LSD	Least Significant digit
MAX	Maximum
MIN	Minimum
AVG	Average
TRIG	Trigger
Vavg	Average voltage
Vmax	Peak voltage
Vp-p	Peak-to-peak voltage
Vrms	Root-mean-square voltage
Hi-Z	Hi input impedance
dB	Decibel
dBV	Decibel volts
dbW	Decibel watts

Table 22.1 – Standard abbreviations used for DMM

Manufacturers will provide instructions on their use.

22.2 Measuring AC Voltage

Digital multimeters with voltage measurement have an auto range facility that allows the instrument to automatically obtain the correct range.

Voltage measuring procedures can vary slightly with different DMMs. Caution should always be taken with any DMM when measuring voltages over 24 V. To measure AC voltages with a DMM, use the following procedure:

- Set the function switch to AC voltage and set the range to the highest voltage setting if the voltage in the circuit is unknown
- plug the black test lead into the common jack
- plug the red test lead into the voltage jack
- connect the DMM test leads to the circuit. Common industrial practice is to connect the black test lead to the grounded (neutral) side of the AC voltage
- read the voltage measurement displayed on the DMM.

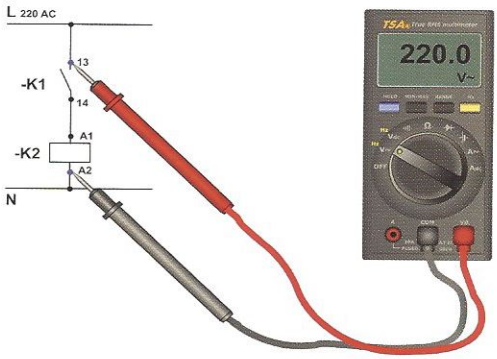


Figure 22.1 – Measuring potential difference across test points –K1/13 and -K2/A2

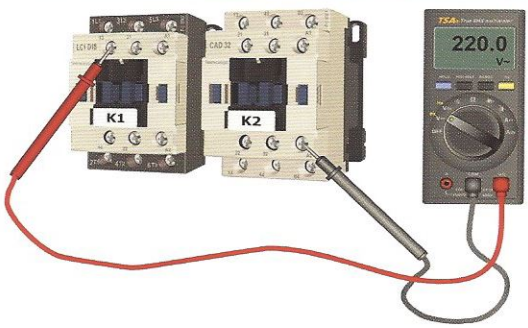


Figure 22.2 – Measuring potential difference in live application across terminals –K1/13 and –K2/A2

Figure 22.1 illustrates the control voltage measurement across -K1 relay terminal 13 and relay –K2 coil terminal A2. A potential difference of 220 V AC should not disappear after contact

-K1/13-14 closes. Figure 22.2 illustrates the same measurement procedure on a live unit's terminals.

22.3 Measuring Resistance

A DMM measures resistance of a circuit or measures resistance of a component removed from a circuit.

To measure resistance with a DMM, use the following procedure:

- Check that all power to the circuit under test is switched off. Always remove the device being tested from the circuit
- set the function switch to 'resistance' mode as required by the DMM. The DMM should display *0L* and the Ω symbol when it is in resistance mode
- plug the black test lead into the common jack
- plug the red test lead into the resistance jack
- ensure that the DMM batteries are in good condition
- connect the leads across the device under test ensuring good contact between the test leads and the component under test
- read the resistance measurement displayed on the DMM
- after completing all resistance measurements, switch the DMM off to prevent battery drain.

Figure 22.3 shows an example of the resistance measurement for Star-Delta starter e-motor W1-W2 winding. It is important to ensure that the three-phase power supply is disconnected before connecting the DMM to the e-motor terminals.

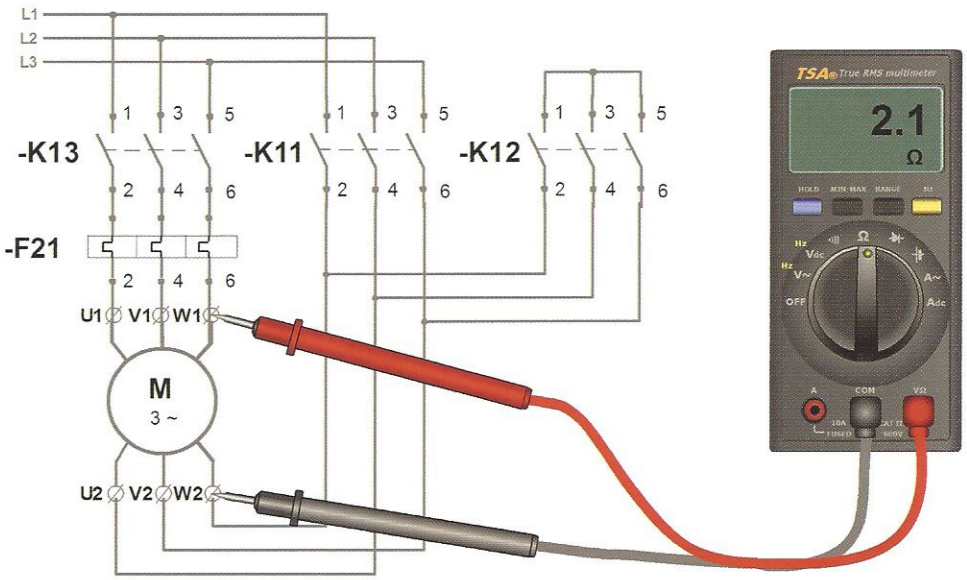


Figure 22.3 – Measuring the impedance of motor winding W1-W2 with the DMM. The check points are determined from the motor starter's diagram

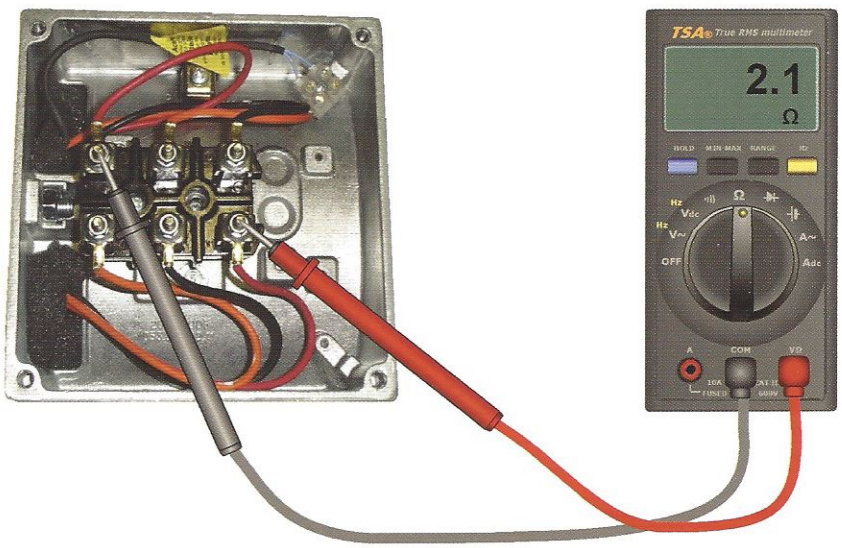


Figure 22.4 – Measuring the impedance across W1-W2 (overview at the motor's terminals)

22.4 Measuring Continuity

Dead circuit testing is performed when the power has been disconnected from the circuit. The most important benefit of disconnecting the power supply during tests is to eliminate any hazardous risks to the environment or person conducting the test.

These tests are carried out if it is uncertain that the electrical path is complete. In short, continuity tests are used to check the integrity of cables, sensor wiring, control wiring accuracy, power lead integrity, switch and discrete sensor pushbutton integrity, and short circuit paths within the control and power lines.

For example, when testing sensor cable conductor integrity (Figure 22.5), the DMM must be set to either the Continuity or Resistance scale. The value, in ohms, that appears on the screen during measurement will depend on the cable length and core section. The DMM in Figure 22.5 shows 0.1 ohms and gives an audible signal indicating a closed path.

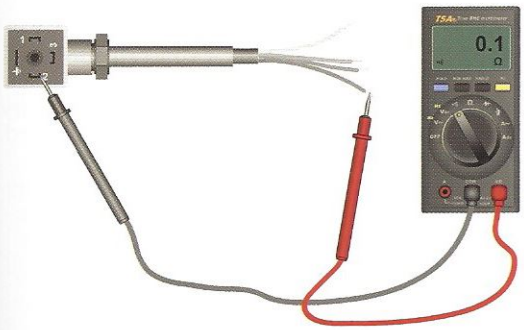


Figure 22.5 – Measuring cable's conductor integrity

The example in Figure 22.6 shows a continuity test conducted for a DOL starter control circuit. Using this test, the continuity of an entire control circuit is checked to ensure that the electrical path from terminal A1 (coil of contactor K1) to start button terminal 4 is complete. In the example, the DMM shows 0.2 ohms, indicating that the path is closed.

22.5 Measuring In-Line Current

Care must be taken to protect the ammeter, circuit and user when measuring AC or DC current with an in-line ammeter.

To measure an in-line current with a DMM, use the following procedure:

- Set the function switch to the proper position for measuring the AC or DC current level (A, mA, or µA) unless the DMM has an automatic current scale
- plug the black test lead into the common jack
- plug the red test lead into the current jack. The current jack may be marked A, mA, or µA
- turn the power to the circuit off and if possible discharge all the capacitors
- open the circuit at the test point and connect the test leads to each side of the opening
- turn the power on to the circuit that is under test
- read the current measurement displayed on the DMM display
- turn the power off and remove the ammeter from the circuit
- restore the connection.

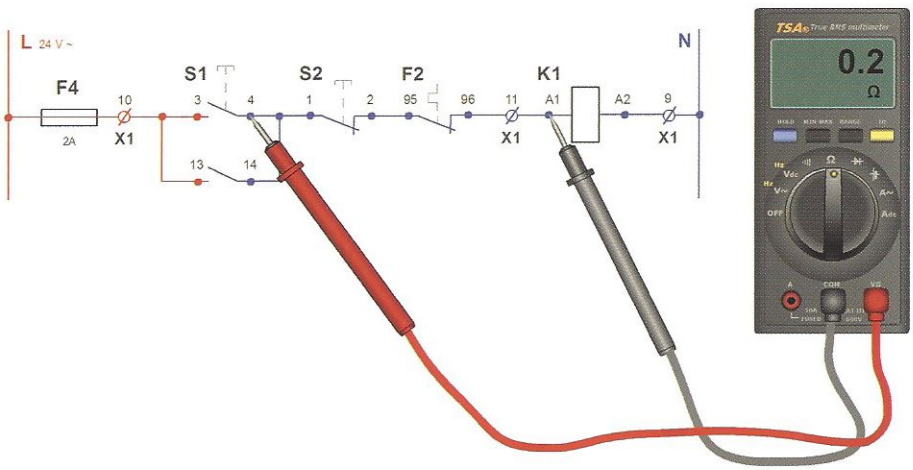


Figure 22.6 – Measuring control circuit continuity

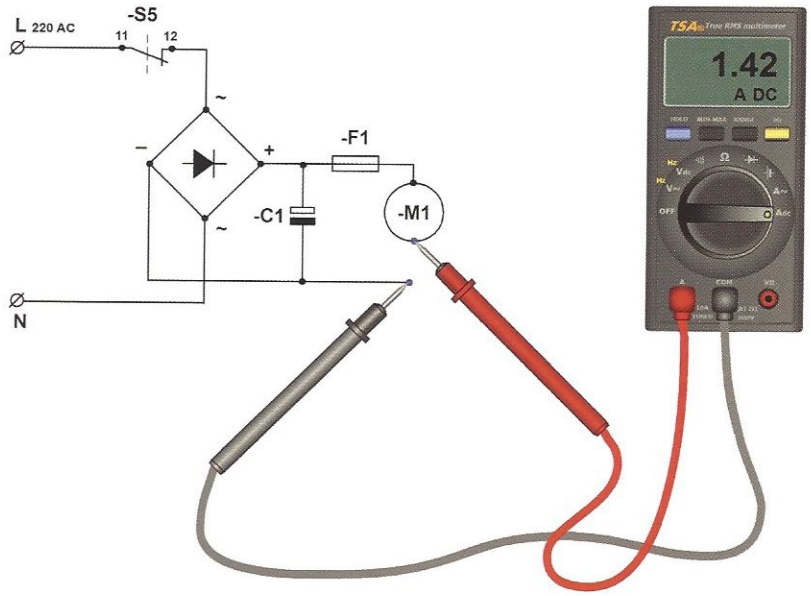


Figure 22.7 – Measuring DC motor's in-line current

22.6 Testing Diodes

A multimeter (set to measure resistance) can be used to determine which end of a diode is the cathode and which is the anode. This is possible because the meter is a voltage source with a different polarity. Externally, the polarity of the meter may be marked positive (+) and negative (-). This is red for positive and black for negative.

When connecting the meter across the diodes, two readings will be given depending on how the leads are connected. One way provides a very low resistance and the other very high.

Figure 22.8a illustrates a fully opened diode with a measured value of 40.1 kΩ. This indicates that the positive lead (red) is connected to the anode and the negative lead is connected to the cathode.

Connected the other way, the meter will show a very high resistance. Figure 22.8b illustrates a fully closed diode with a measured value of infinity ('0L' shown on the screen of a multimeter represents the infinity value in MΩ). This indicates that the positive lead is connected to the cathode and the negative lead is connected to the anode.

To measure the voltage-drop across a diode's p-n junction, the multimeter is set to diode-test (Figure 22.9). In this test the DMM drives the DC-current through the p-n junction while measuring the voltage drop across it. If the value remains within the range of 0.5-0.8 V DC, the diode is considered as being in good condition.

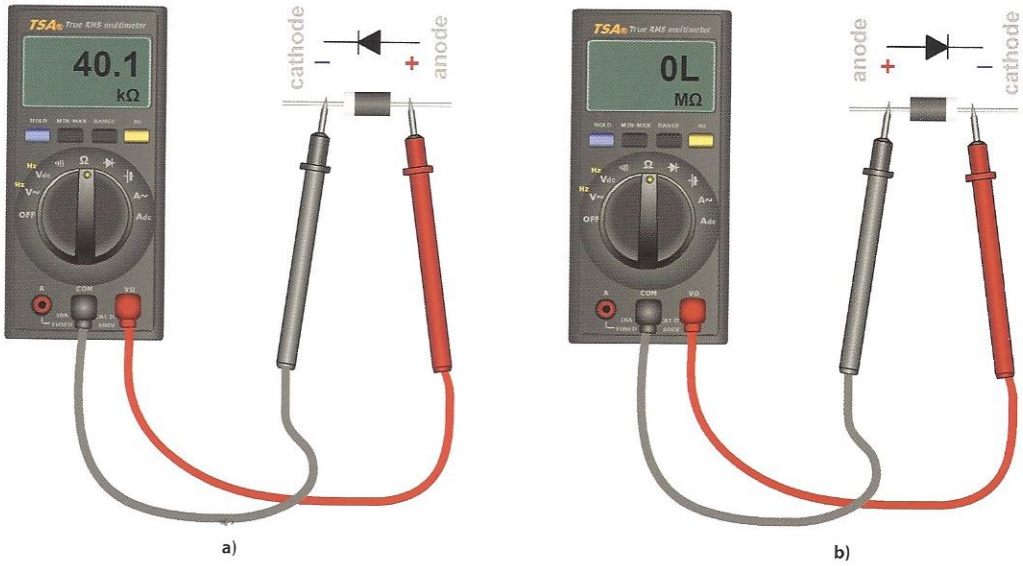


Figure 22.8 – Determining the diode polarity

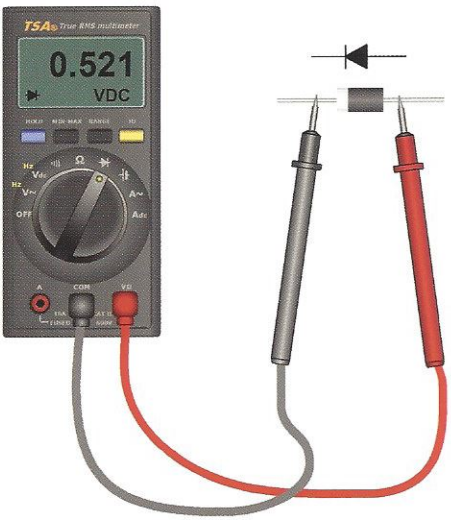


Figure 22.9 – Checking a diode's p-n junction voltage drop

To reverse the DMM's leads across the healthy diode, the display should indicate over-range, ie the range is higher than the parameters being tested. If the DMM registers over-range in both directions, the diode is non-functional (p-n junction has an open-circuit). If the display indicates that the voltage is less than 1 V DC in both directions, the diode is non-functional (the p-n junction has a short circuit).

Another way of testing a diode's p-n junction for open and short circuits is to measure the resistance across it in both directions (Figure 22.9). When the diode is good, there should be low-resistance in one direction and relatively high-resistance in the opposite direction. If the diode is short circuited , the multimeter will register low-resistance in both directions. If the diode is opened, the DMM will register high-resistance in both directions.

23 GL Regulations. Machinery Class Notations

Rules for Classification and Construction Ship Technology

Edition 2008

Germanischer Lloyd

1 Seagoing Ships
4 Automation

Section 1
General Rules and Instructions

B. Class Notations

Machinery installations which comply with GL's Rules for Construction for automated and/or remotely controlled systems are given the following additions to the Class Notation:

1. AUT
The machinery installation has been designed to operate in an unattended machinery space so that no control and maintenance operations are required for at least 24 hours.

2. AUT-nh
This denotes the period during which no control and maintenance operations are necessary, whereby ***nh*** means that the machinery installation may be left unattended for *n* hours (h).

3. AUT-Z
Class Notation for machinery systems on ships with a permanently attended machinery control room for centralized control, remote control of the propulsion plant from the bridge or facilities for maneuvering the ship from the machinery control room.

Section 2
Range of Control and Monitoring Equipment

A. Machinery with Class Notation *AUT*

1. The propulsion plant and the auxiliary equipment necessary for operation is to be prepared free of maintenance for 24 hours.
2. Service tanks are to be refilled automatically or are to be so sized that they do not require topping up for 24 hours. A reserve capacity of 15 % is also to be provided.
3. A remote control system for the propulsion plant is to be installed on the bridge in accordance with Section 5, A.
4. A safety system for the propulsion plant is to be installed in accordance with Section 4, C. and 5, B. with regard to diesel engines and 5, C. with regard to steam turbine plants.
5. A machinery alarm system is to be provided in accordance with Section 4, A. and a duty alarm system in accordance with Section 4, B.
6. An alarm point/data recording device is to be provided in accordance with Section 4, A.14. for propulsion output above 1500 kW; see Section 8.
7. A communication system is to be installed in accordance with Section 4, F.
8. Boilers and thermal oil systems are to be equipped as described in Section 5, C. and 6, D., E.
9. Auxiliary diesels are to be equipped as described in Section 6, B.
10. Auxiliary turbines are to be equipped as described in Section 6, C.
11. Starting air and control air vessels must be filled-up automatically.
12. Fuel and lubrication oil purifiers are to be of self-cleaning type, unless no operation or maintenance is required to keep them in service during the period of which the machinery spaces are to remain unattended according to the Class Notation.
    Purifier systems are to be designed in accordance with Section 6, F.
13. Air compressors are to be designed in accordance with Section 6, G.
14. For essential auxiliary machinery, a stand-by circuit is to be provided in accordance with Section 4, H. and 8, I.
15. Where required for system operation, pressures and temperatures are to be controlled automatically.
16. Valves in the shell which are open during machinery operation must be accessible and must be capable of being operated from a safe height above the floor plates.
17. Engine room bilges and bilge wells are to be designed in accordance with Section 6, H.
18. Interruptions in the power supply are to be avoided or overcome in accordance with Section 4, H.2.
19. A fire alarm and detection system is to be provided in accordance with Section 4, G.
20. Approved fire extinguishing equipment is to be provided in the engine and boiler spaces. See Chapter 2 – Machinery Installations, Section 12 for details of the design.
21. A remote start system for one of the main fire pumps is to be installed on the bridge and where applicable at the main fire control station. The associated valves are to be equipped with an instruction table: "Keep valves open at all times!"

B. Machinery with Class Notation *AUT-nh*

1. For the range of equipment see A.3. to 21.
2. The propulsion plant and the auxiliary equipment necessary for operation is to be prepared free of maintenance for at least the length of time in which the machinery spaces may be left unattended in accordance with their Class Notation.

3. Service tanks are to be refilled automatically or are to be designed so that they do not require topping up during the period in which the machinery space is left unattended. A reserve capacity of 15 % is also to be provided.

C. Machinery with Class Notation *AUT-Z*

1. Facilities are to be provided so that the propulsion system can be remotely controlled from the bridge as described in Section 5, A. or from a central machinery control station to enable the ship to be maneuvered, without restriction, by one person.
2. The machinery control station is to be installed in a closed machinery control room.
3. All the operating data of the propulsion plant, together with the operating status of the auxiliary machinery essential to the propulsion plant are to be displayed at the control station.
4. A safety system in accordance with Section 4, C. and 5, B. is to be provided for the propulsion plant and for engine systems and steam turbine plant according to Section 5, C.
5. A machinery alarm system is to be fitted in accordance with Section 4, A. and Section 8.
6. If the propulsion plant is remotely controlled from the bridge, the machinery alarms listed in Section 8, at least those alarms which require a shut down or a power reduction, are to be announced at the control station as a "stop engines" or "reduce speed or power" group alarm.
7. Boilers and thermal oil systems are to be designed in accordance with Section 5, C. and Section 6, D. and E. The steam pressure is to be continuously displayed at the control station.
8. The auxiliary machinery which is essential to the main propulsion plant and their standby units must be capable of being started and stopped from the control station. Further details are given in Section 8, I.
9. It must be possible to start and connect the diesel generators from the control station.
10. Purifier systems are to be designed in accordance with Section 6, F.
11. Air compressors are to be designed in accordance with Section 6, G.
12. Where required for system operation, pressures and temperatures are to be controlled automatically.
13. A fire alarm and detection system is to be provided in accordance with Section 4, G.
14. Engine room bilges and bilge wells are to be designed in accordance with Section 6, H.

Section 7
Tests

D. Tests on Board
1. General

Tests comprise:
- tests during construction/installation
- tests during commissioning
- tests during sea trials
- repeated tests

The test procedures are based on forms *AUT M* and *AUT D* for engine driven systems and steam driven systems respectively.

1.1 AUT 1
Form AUT 1 - "Details on Automatic and Remote Controls of Propelling Machinery" is used to apply for the relevant Class Notation. Concept approval for the whole system is given due to the information provided.

1.2 AUT 2
Form AUT 2 - "Test report for Automatic and Remote Controls of Propelling Machinery" is used for the operational testing of the whole system. Following successful completion of the tests, the relevant Class Notation is issued.

E. Type Approvals

1. The following installations, equipment and assemblies are subject to mandatory type testing.
2. Installations, equipment and assemblies which are subject to type testing:

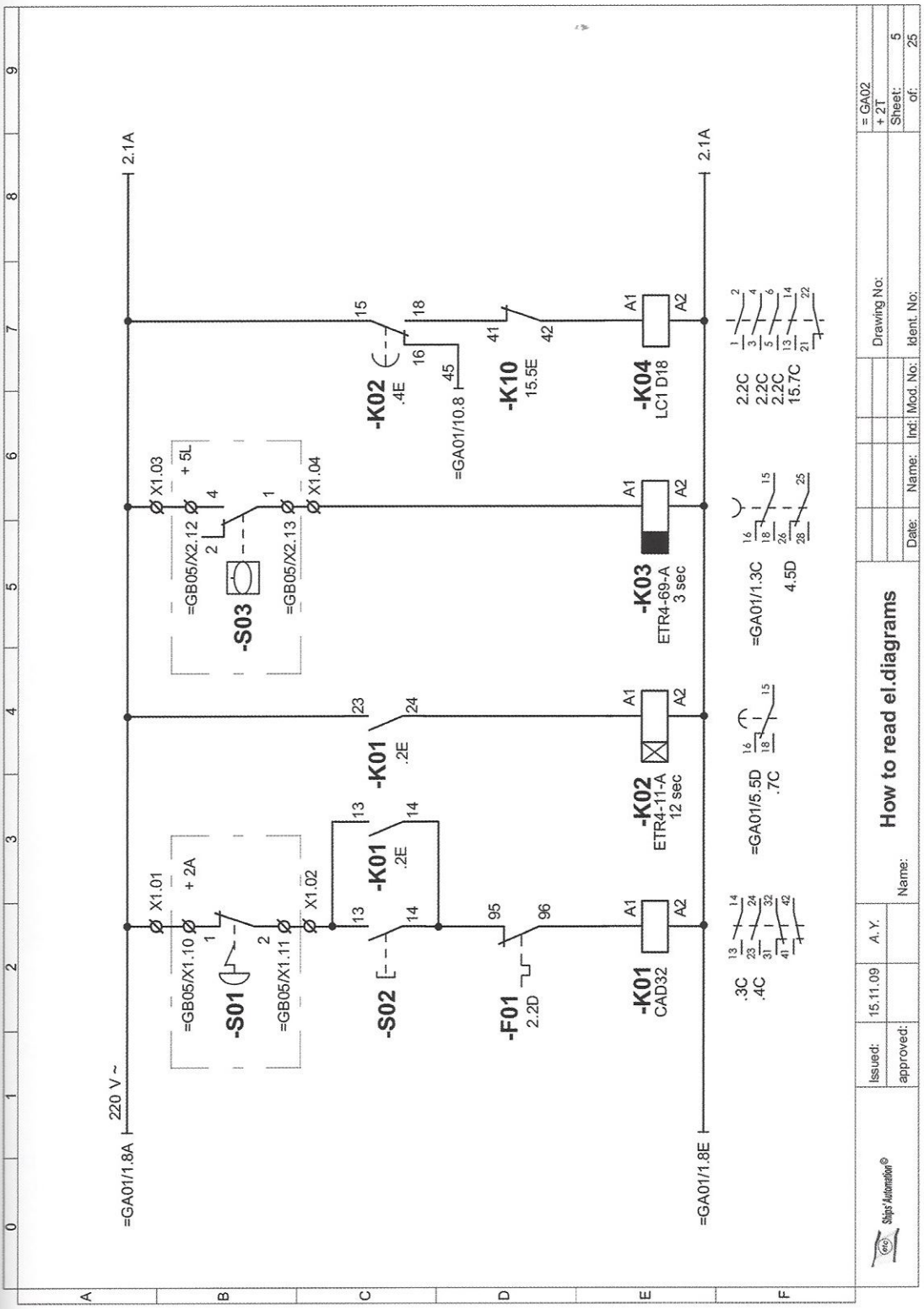
- computer systems for open and closed loop controls and monitoring of equipment essential to ship operation;
- remote control systems for the main propulsion plant;
- fire detection systems and sensors;
- sensors and actuators for specified automation equipment;
- machinery alarm systems;
- duty alarm systems;
- safety devices;
- safety systems;

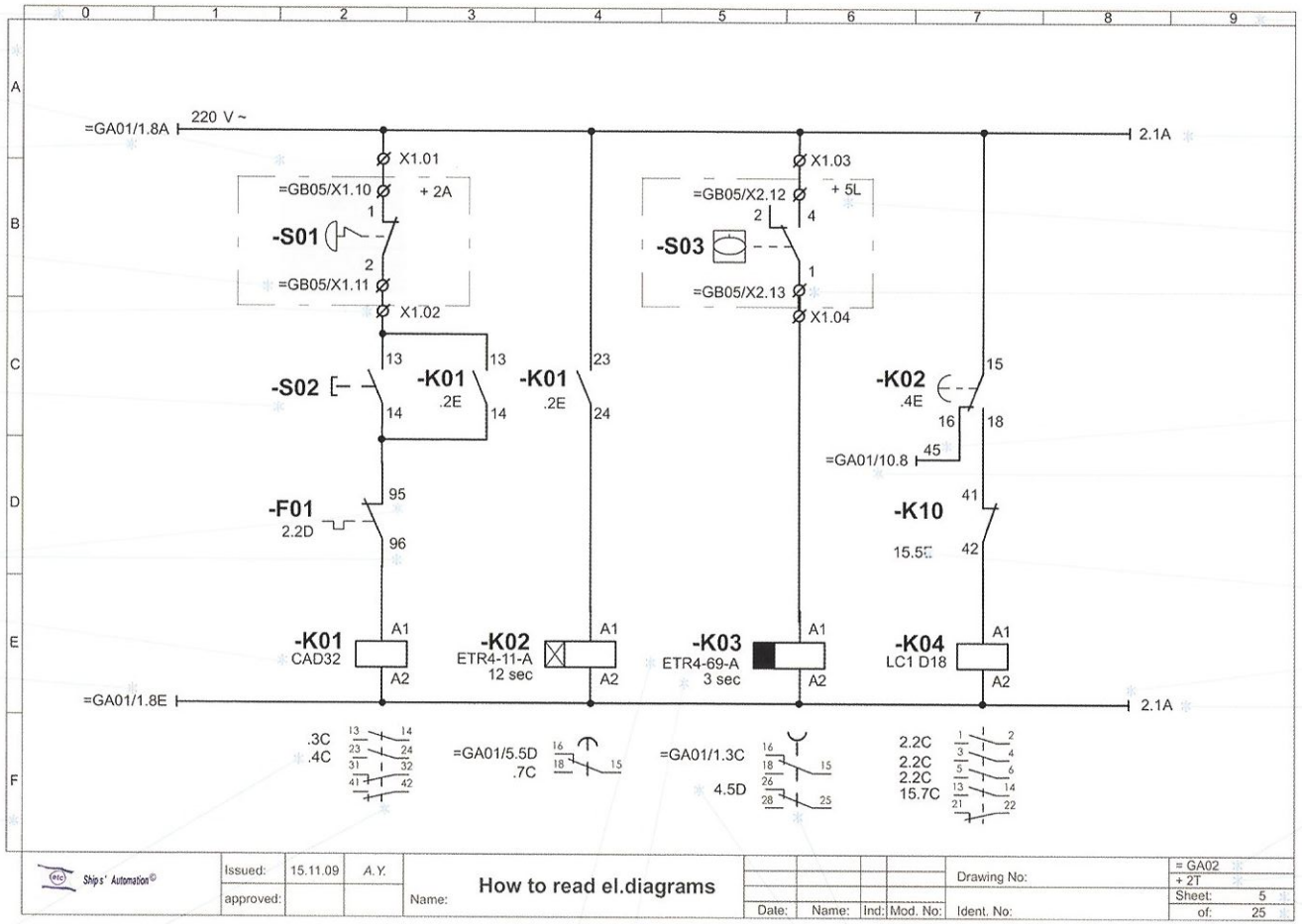
3. As an alternative to the type tests specified, particular tests may be carried out, where justified in individual cases, in the presence of a GL Surveyor, with the prior consent of GL.

This is an extract taken from GL regulations 2008, www.gl-group.com, and so must not be relied on or be considered as all inclusive.

Appendices

Appendix 1 – How to Read Electrical Diagrams





0... 9 - Diagrams sections

A... F - Diagrams segments

Diagram's square .2B

Line break continuation reference (group =GA01; sheet 1, section 8A)

Terminal X1.11 reference (within function group =GB05)

Terminal X1.02 reference (within current group =GA02)

-S02
- unit's qualifying symbol

95 - 96 Overload's relay contacts' reference numbers

CAD 32 - relay's type

Line break continuation reference (group =GA01; sheet 1, section 8E)

A... F - Diagrams segments

.4C -K01 contact 23-24 wiring reference (same sheet, section 4C)

-K01 relay contacts' legend for references

ETR4-69-A Timer's type reference

3sec - Time delay's setpoint

-K03 Time relay contacts' legend for references

-K03 / contact 25-26 wiring reference (sheet 4, section 5D)

0... 9 - Diagrams sections

Line break continuation reference (sheet 2, section 1A)

+ 5L - Function group (location)
+ qualifying symbol

Terminal X2.13 reference (within function group =GB05)

Conductor's tag identifier

Line break continuation reference (plant =GA02, sheet 10, section 8)

15.5E - Relay coil's reference (sheet 15, section 5E)

Line break

Line break continuation reference (sheet 2, section 1A)

=GA02 - Plant identification code (diagram's group code)
= qualifying symbol

+2T - Function group (assembly / location)

Sheet: 5 - Sheet's number

of: 25 - Number of sheets within group =GA02

Appendix 2 – Control Elements (European Diagram Symbols)

Instruments for measurement and indication.

Voltmeter

Ammeter

Double frequency meter

Power meter

Synchronoscope

Resistance insulation meter

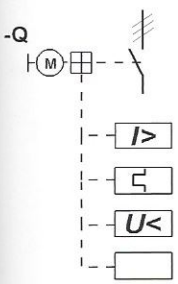
Power Factor meter

Phase sequence indicator

Circuit-breakers, Interrupters, Releases

Busbar cutter

Circuit-breaker (single line diagram representation symbol)



Circuit-breaker with energy stored mechanism driven with motor

Magnetic overcurrent release

Thermal overload release

Undervoltage release

Shunt release

Reverse power relay

Underfrequency relay

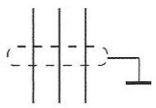
Connections

Conducting connection

3-phase (busbar, cable)

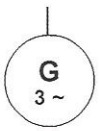
2-phase (busbar, cable)

Plugs

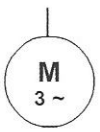


Screened conductors (screened cable)

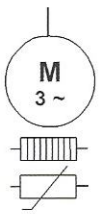
Generators, Consumers, Transformers



Generator

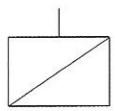


Motor

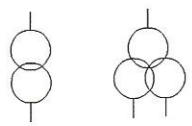


Motor with space heater and PTC probe

Consumer (motor starter, switchgear, ...)



Distribution board

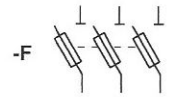


Transformer

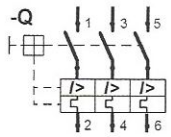
Current transformer

Fuses and Circuit-breakers

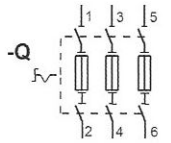
Fuse



Fuse breaker

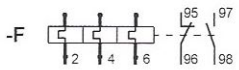


Automatic air circuit-breaker

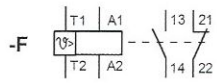


Load switch with fuses

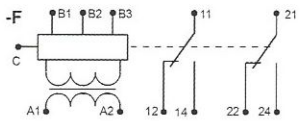
Protection and Monitoring Relays



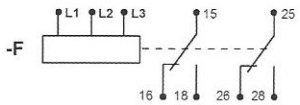
Thermal overload relay



PTC relay

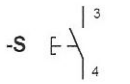


Current monitoring relay

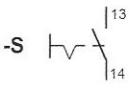


Phase imbalance relay

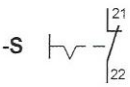
Switches



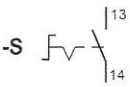
Pushbutton, spring-return type, Normally Open



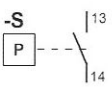
Selector switch, manually operated, Normally Open



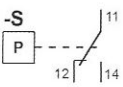
Selector switch, manually operated, Normally Closed



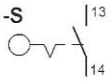
Rotary selector switch, manually operated, Normally Open



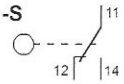
Pressure switch, Normally Open



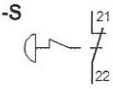
Pressure switch, Change Over



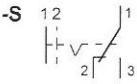
Key operated switch



Limit switch (end switch), Change over

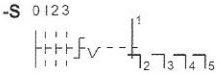


Emergency stop mushroom button, latching type

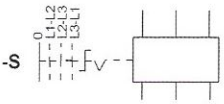


Change over switch

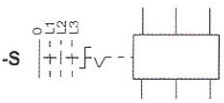
Change over switch with 0-position



4-step rotary switch



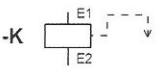
Change over switch for voltmeter



Change over switch for ammeter

Relays, Contactors

Contactor coil, Relay coil



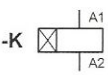
Latching relay

Flasher relay coil

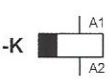
Auxiliary contact, Normally Open

Auxiliary contact, Normally closed

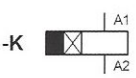
Auxiliary contact, Change over



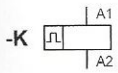
Delay On timer



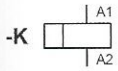
True Delay Off timer



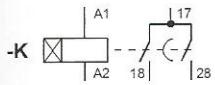
Delay On-Off timer



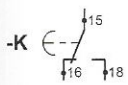
Interval timer



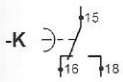
Multifunction timer



Star-Delta timer



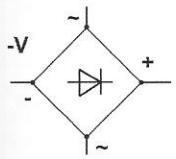
Delayed On changeover contact



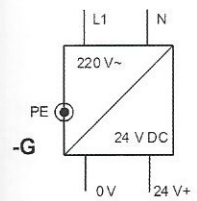
Delayed Off changeover contact

Units

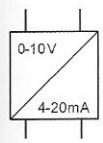
Semiconductor diode



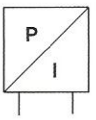
Full wave rectifier



Power supply

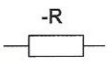


Signal converter

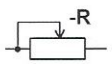


Pressure Transducer

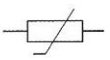
Diverse



Resistor

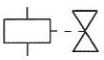


Potentiometer



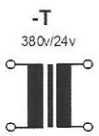
PTC sensor

Space heater



Solenoid valve

El. mechanical brake

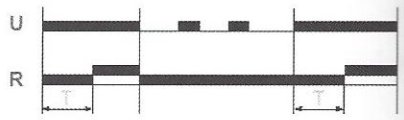
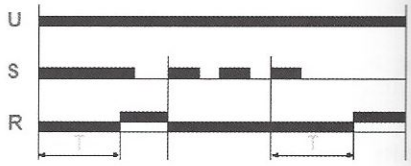
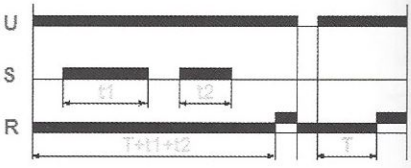
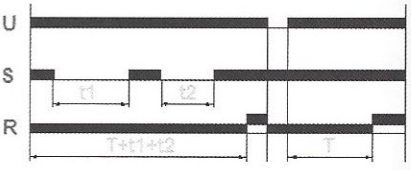
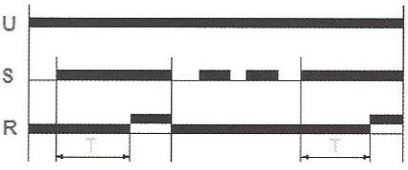
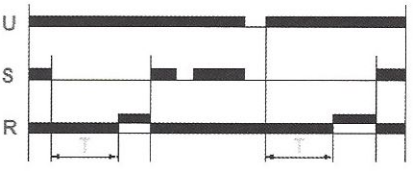
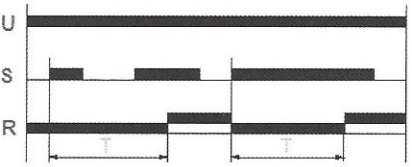


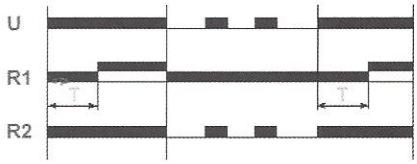
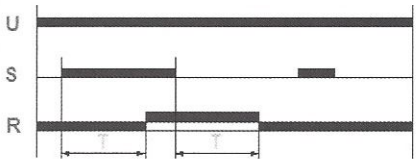
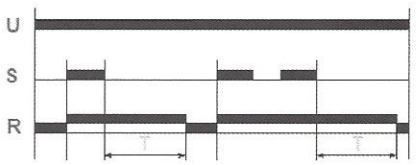
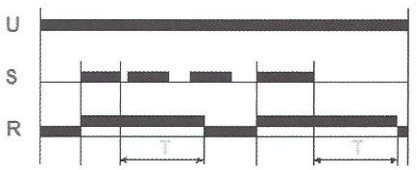
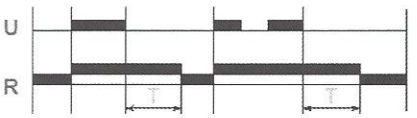
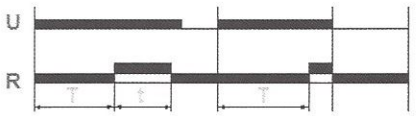
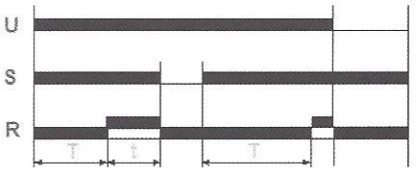
Voltage step-down transformer

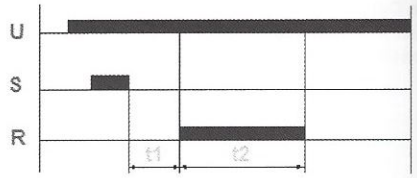
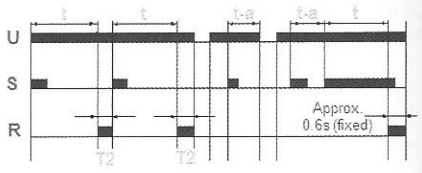
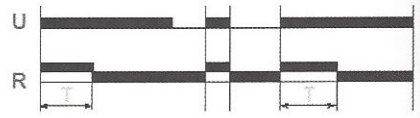
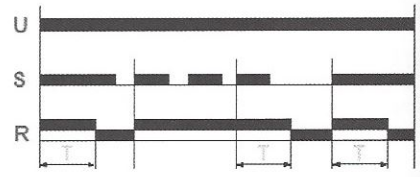
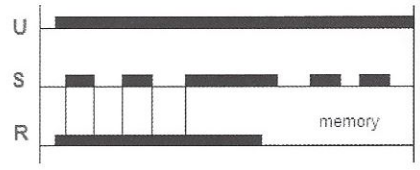
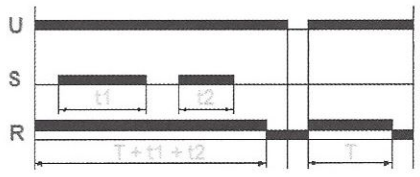
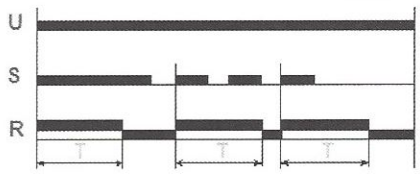
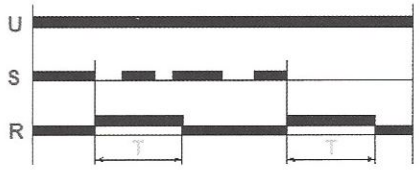
Current transformer

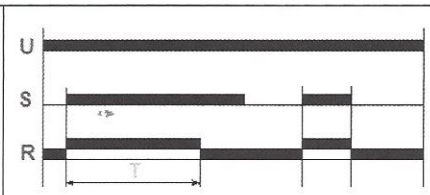
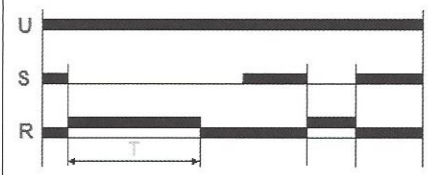
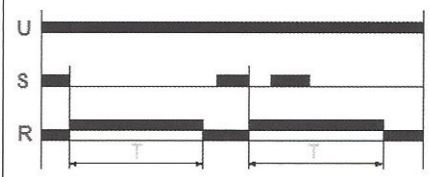
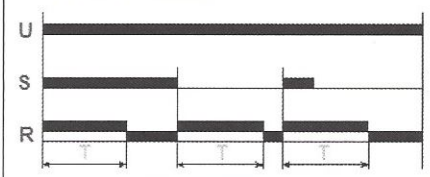
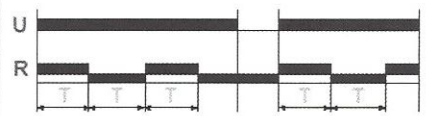
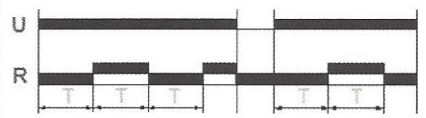
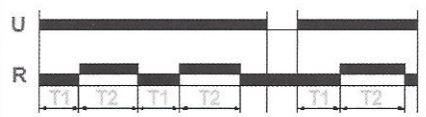
Appendix 3 – Timer Functions

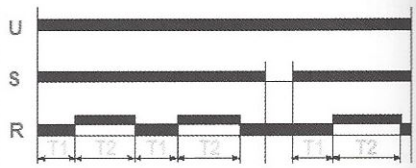
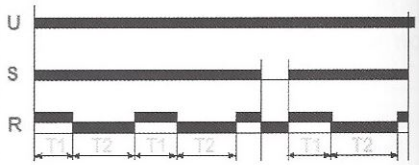
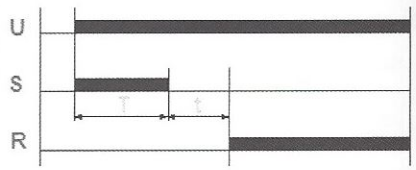
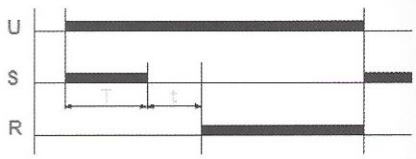
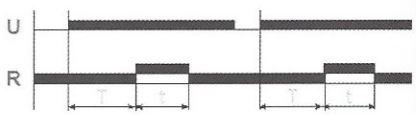
Note: *The functions detailed below have no industry standard titles, so they may be titled differently by different manufacturers.*

On delay	The timing period starts when the supply voltage is applied. After the pre-set time period has elapsed, the output relay 'R' is energised. 'R' will stay energised until the supply is interrupted, if the supply is interrupted then 'R' returns to its original state. Regardless of when this occurs the timer starts from the beginning of the cycle all over again.	
On Delay ***(Control Switch Resetable)***	The timing period starts when the supply voltage is applied. The output relay 'R' will energise after this period has elapsed, unless the control switch input 'S' is repeatedly closed and then opened. The timer monitors the leading edges of the control switch pulses. The Pulse length, therefore, must be shorter than that of the timer period set.	
On Delay ***(Control Switch Interruptible) Type 1***	The timing period starts when the supply is applied to the timer with the control switch 'S' open. Closing 'S' causes the timer to pause its timing, without resetting. Timing resumes once 'S' is opened again. Therefore, the total time taken for the output relay 'R' to energise is the preset timing period plus the sum of the time 'S' was closed. Removal of the supply will cause the timer to reset the timing period back to the preset value.	
On Delay ***(Control Switch Interruptible) Type 2***	The timing period starts when both the supply and control switch are energised. Opening the control switch suspends timing but does not reset the time sequence. Therefore, the total time taken before the delayed contact changes state is the preset time plus any time that the control switch is open. Interrupting the supply resets the timer. If the control switch remains closed during and after the reset, timing will resume immediately when the supply is resumed.	
On Delay ***(Constant Supply) Type 1***	A permanent supply is required. A control switch 'S' is used to control the timer function. The delay period starts once switch 'S' is closed. Once the preset period of time has elapsed then output relay 'R' energises. Opening 'S' will cause 'R' to de-energise, and likewise closing it again will start the timing period from the beginning, this action may be performed at any point of the timing cycle.	
On Delay ***(Constant Supply) Type 2***	Timing will commence when the supply is present and switch 'S' is open. After the time period has elapsed, the output relay 'R' will energise. If, however, 'S' is closed then the timing period resets to the beginning of the cycle. Timing will restart only when 'S' has been opened. Therefore, there are 2 ways this timer can be controlled, either by opening and closing 'S' or with the interruption of the supply voltage to the timer with switch 'S' open.	
On Delay ***(Constant Supply) Type 3***	A permanent supply is required. The timing period starts when the control switch 'S' is closed and will continue irrespective of any further changes to 'S'. After the elapsed time output relay 'R' energises. To reset the timer, switch 'S' must be opened. This does not de-energise the relay. It is de-energised and the function repeated when switch 'S' is reclosed. (ie, the timer must see a leading edge).	

On Delay *with Instantaneous Contact*	The timing period starts when the supply voltage is applied. The output relay 'R'2 energises immediately. After the pre-set time period has elapsed, the output relay 'R'1 and 'R'2 will stay energised until the supply is interrupted. If the supply is interrupted 'R'1 and 'R'2 return to their original state. Regardless of when this occurs, the timer starts from the beginning of the cycle.	
On-Off Delay *(Constant Supply)*	A permanent supply is required. Control switch 'S' controls the timer function. When switch 'S' is closed, the timer period starts. Once this has elapsed, output relay 'R' energises. If switch 'S' is opened the relay remains energised for the same length of time as the first preset time period. Once this too has elapsed, the relay de-energises and remains so until switch 'S' is closed again. Closing switch 'S' and then opening it before the time period has elapsed will not cause activation of 'R'.	
Off Delay *(Constant Supply) Type 1*	A permanent supply is required. The timer function is triggered by using control switch 'S'. When 'S' is closed, the output relay 'R' will energise immediately. The timing period will start once 'S' is opened, with 'R' still energised. Once this period has elapsed then 'R' will de-energise. Closing 'S' at any time in the cycle will cause 'R' to energise, if it is not already, and the timing period to start from the beginning.	
Off Delay *(Constant Supply) Type 2*	A permanent supply is required. The timer function is triggered by using control switch 'S'. When the switch is closed, the output relay 'R' will energise immediately. Once the timing period has started further actions of 'S' will have no effect. However, once the timing cycle has been completed, the process may be started again by closing 'S'. While the timer is executing this function, the only way to reset the timer is to interrupt the supply.	
True Off Delay	When the supply is applied, the timer output relay 'R' will energise. When the supply is removed, 'R' will stay energised for the preset time period. Re-applying the supply will cause 'R' to energise again (if it is not already) and the timing period starts when the supply is disconnected again. A point to note is that the timer needs to store the energy to retain the output relay in the energised state after the supply has been removed. This will reflect in the length of time the supply has to be applied.	
Delayed Pulse *(Constant Supply)*	The timing period starts when the supply is applied to the timer. After the preset has elapsed, the output relay 'R' will energise for the preset pulse duration. To reset the timer the supply must be interrupted. If this interruption occurs during the pulsed output then the relay will de-energise and the timer will reset. ('T' is the delay duration and 't' is the pulse duration).	
Delayed Pulse *(Remote Trigger)*	The timing period will start when control switch 'S' is closed with the supply connected. After the preset time has elapsed, the output relay 'R' will energise for the pre-selected pulse duration. To reset the timer, either control switch 'S' is opened or the supply has to be interrupted. If this action occurs during the pulsed output cycle then the relay will de-energise and the timer will reset. ('T' is the delay duration and 't' is the pulse duration).	

Delayed Pulse ***(Constant Supply) Type 1***	Supply to the unit must be continuous. On closure of the 'S' the time period 't1' starts to run. On completion of 't1', the relay 'R' energises immediately and the time period 't2' starts to run. On completion of 't2', the relay 'R' de-energises. The control contact 'S' has no effect until 't1' + 't2' have completely expired.	
Delayed Pulse ***(Constant Supply) Type 2***	The supply is connected permanently to the timer. A switch 'S' is used to control the timer function (refer to the timing diagram). The delay time period starts closing. After an elapse of time set the output relay 'R' is energised for a fixed period, T2. Opening switch 'S' during time period 'T' has no effect, but re-closing will initiate timing 'T' once more.	
On Pulse	When the supply is connected the output relay 'R' energises and the timing function starts. After the preset timer period has elapsed 'R' de-energises. Interrupting the supply resets the time period. If this interruption occurs before the period has elapsed, 'R' will de-energise and the timing period resets.	
On Pulse ***(Control Switch Resetable) Watchdog***	Output relay 'R' will energise as soon as the supply is applied to the timer if control switch 'S' is closed, and will start to time out unless control switch 'S' is opened and then closed repeatedly within the time period. The timer will not time out while it sees a continuous series of pulses. If 'R' does de-energise, the timer can be reset by closing control switch 'S' and repeating the process as before.	
On Pulse ***(Supply Reset)***	On application of supply voltage the relay energises. The first pulse of 'S' starts the time period. Receiving pulses during the time period extends it and 'R' stays energised. Receiving no pulses during the time period completes it and 'R' de-energises. 'R' stays latched until the supply voltage has been interrupted.	
On Pulse ***(Control Switch Interruptible)***	When the timer supply is connected, output relay 'R' energises and the timer period starts. If control switch 'S' is closed then the timing is suspended. Only when 'S' is open again will the timing resume. Therefore the total time output relay 'R' is energised equal to the preset time period plus the sum of the time 'S' is closed. Interrupting the supply will reset the timer.	
On Pulse ***(Constant Supply) Type 1***	A permanent supply, is required. Control switch 'S' controls the timers function. When 'S' is closed, output relay 'R' energises and will then time out irrespective of any further action of 'S'. To re-energise 'R', 'S' must be opened and then closed once 'R' has de-energised.	
On Pulse ***(Constant Supply) Type 2***	A permanent supply is required. Control switch 'S' controls the timer's function. When 'S' is opened, output relay 'R' energises and will then time out irrespective of any further action of 'S'. To re-energise 'R', 'S' must be closed and then opened after 'R' has de-energised.	

On Pulse ***(Constant Supply) Type 3***	A permanent supply is required. Control switch 'S' controls the timers function. When 'S' is closed and remains closed the output relay 'R' will energise and only de-energise after it has timed out. If 'S' is opened during the timing period, relay 'R' resets.	
On Pulse ***(Constant Supply) Type 4***	A permanent supply is required. Control switch 'S' controls the timers function. When 'S' is opened and remains open, the output relay 'R' will energise and only de-energise after it has timed out. If 'S' is closed during the timing period, relay 'R' resets.	
Off Pulse	A permanent supply is required. Control switch 'S' controls the timers function. Closing control 'S' has no effect on output relay 'R'. However when 'S' is opened, 'R' will energise and starts the time period, after which it will de-energise. If switch 'S' is pulsed during that timing period it will have no effect on relay 'R'. Closing and then re-opening 'S' will repeat the timing operation after the completion of the timing period.	
On-Off Pulse	A permanent supply is required. Control switch 'S' controls the timers function. The output relay 'R' is energised by either opening or closing control switch 'S'. Once a timing period has started it cannot be interrupted by changing the state of 'S'.	
Symmetrical Recycler ***Pulse Start***	When the supply is connected to the timer, it will energise the output relay 'R' for the preset time and then de-energise for the same preset time interval. This operation will repeat indefinitely until the supply is removed. The timer will always start at the same point of the cycle regardless of where it was when the supply was removed. The unit can be either pause or pulse start depending on wiring or type.	
Symmetrical Recycler ***Pause Start***	When the supply is connected to the timer, the preset time will elapse before output relay 'R' energises for the same preset time interval. This operation will repeat indefinitely until the supply is removed. The timer will always start at the same point of the cycle regardless of where it was when the supply was removed. The unit can be either pause or pulse start depending on wiring or type.	
Asymmetrical Recycler ***Pause Start***	When the supply is connected to the timer, the first preset time will elapse before the output relay 'R' will energise. The output will stay energised for the second preset time period (which is set independently to the de-energised time) it will return to the de-energised state and repeat the whole process over again. This is continued until the supply is removed. The timer will always start in the de-energised part of the cycle regardless of which state it was in when the supply was removed.	
Asymmetrical Recycler ***Pulse Start***	When the supply is connected to the timer, the output relay will energise for the first preset time. Once this has elapsed, the output will de-energise and stay de-energised for the second preset time period (which is set independently to the energised time). Once this has elapsed then it will return to the energised state and repeat the whole process over again, until the supply is removed. The timer will always start in the energised part of the cycle regardless of which state it was in when the supply was removed.	

Asymmetrical Recycler ***(Constant Supply) Pause Start***	A permanent supply is required. The timer function is triggered by the use of a control switch 'S'. When 'S' is closed, the output relay 'R' will remain de-energised while the first preset time period elapses. Once this time period has elapsed, 'R' will energise for the second preset time period (which is set independently). Once this second time period had elapsed then 'R' will de-energise and the cycle will start from the beginning again. If 'S' is opened, the cycle will stop, with it starting in the de-energised state when the switch is closed again.	
Asymmetrical Recycler ***(Constant Supply) Pulse Start***	A permanent supply is required. The timer function is triggered by the use of a control switch 'S'. When 'S' is closed, the output relay 'R' will energise while the first preset time period elapses. Once this time period has elapsed, 'R' will de-energise for the second preset time period (which is set independently). Once this second time period had elapsed then 'R' will energise and the cycle will start from the beginning again. If 'S' is opened, the cycle will stop, with it starting in the energised state when the switch is closed again.	
Star Delta ***Type 1***	This function of a timer has 2 sets of normally open contacts. The timing period starts when the supply is connected. At this point the first output relay 'R1' will energise. This is used to control the 'STAR' contactor. After the preset time interval, the contacts will open. A preset dwell time will elapse after which the second output relay 'R2' will close.	
Star Delta ***Type 2***	This type of timer uses 2 sets of contacts. One being normally open and the other is normally closed. Alternatively, 2 sets of changeover contacts may be used. The timing period starts when the supply is applied. After the preset interval has elapsed, the normally closed contact will energise, opening the circuit. This is used to control the 'STAR' contactor. After the preset dwell time has elapsed, the normally open contacts will close, this is used to control the DELTA contactor. The timer will reset itself when the supply is removed. ('t' is the dwell time).	
Star Delta ***Type 3***	This function only employs one normally closed contact. This has to be wired to a suitable control circuit. When the supply is applied, the contact remains closed for the delay period set on the unit, time 'T'. At the end of the time period, the contact opens for a fixed period of time (manufacturer preset, time 't') and then recloses.	

RS Components Ltd [http://no.rs-online.com]

Appendix 4 – Rated Currents of Three-phase Motors

(Guidelines for squirrel-cage electric motors)

Minimum fuse size for the protection of three-phase motors.
The maximum size is governed by the requirements of the associated switchgear or overload relay.

Motor rating		230 V			400 V			690 V		
		Rated motor current	Fuse		Rated motor current	Fuse		Rated motor current	Fuse	
			Starting direct	Y/Δ		Starting direct	Y/Δ		Starting direct	Y/Δ
kW	P.F.	A	A	A	A	A	A	A	A	A
0.06	0.7	0.37	2	-	0.21	2	-	0.12	2	-
0.09	0.7	0.54	2	-	0.31	2	-	0.18	2	-
0.12	0.7	0.72	4	2	0.41	2	-	0.24	2	-
0.18	0.7	1.04	4	2	0.6	2	-	0.35	2	-
0.25	0.7	1.4	4	2	0.8	4	2	0.5	2	-
0.37	0.72	2	6	4	1.1	4	2	0.7	2	-
0.55	0.75	2.7	10	4	1.5	4	2	0.9	4	2
0.75	0.79	3.2	10	4	1.9	6	4	1.1	4	2
1.1	0.81	4.6	10	6	2.6	6	4	1.5	4	2
1.5	0.81	6.3	16	10	3.6	6	4	2.1	6	4
2.2	0.81	8.7	20	10	5	10	6	2.9	10	4
3	0.82	11.5	25	16	6.6	16	10	3.8	10	4
4	0.82	14.8	32	16	8.5	20	10	4.9	16	6
5.5	0.82	19.6	32	25	11.3	25	16	6.5	16	10
7.5	0.82	26.4	32	25	15.2	32	16	8.8	20	10
11	0.84	38	80	40	21.7	40	25	12.6	25	16
15	0.84	51	100	63	29.3	63	32	17	32	20
18.5	0.84	63	125	80	36	63	40	20.9	32	25
22	0.84	71	125	80	41	80	50	23.8	50	25
30	0.85	96	200	100	55	100	63	32	63	32
37	0.86	117	200	125	68	125	80	39	80	50
45	0.86	141	250	160	81	160	100	47	80	63
55	0.86	173	250	200	99	200	125	58	100	63
75	0.86	233	315	250	134	200	160	78	160	100
90	0.86	279	400	315	161	250	200	93	160	100
110	0.86	342	500	400	196	315	200	114	200	125
132	0.87	401	630	500	231	400	250	134	250	160
160	0.87	486	630	630	279	400	315	162	250	200
200	0.87	607	800	630	349	500	400	202	315	250
250	0.87	-	-	-	437	630	500	253	400	315
315	0.87	-	-	-	544	800	630	316	500	400
400	0.88	-	-	-	683	1000	800	396	630	400
450	0.88	-	-	-	769	1000	800	446	630	630
500	0.88	-	-	-	-	-	-	491	630	630
560	0.88	-	-	-	-	-	-	550	800	630
630	0.88	-	-	-	-	-	-	618	800	630

Notes:

The motor currents apply to normal, internally ventilated and enclosed fan-cooled three-phase motors at 1500 rpm.

***DOL starting:** Maximum starting current 6 × rated motor current. Maximum starting time 5 seconds.*

***Y/Δ starting:** Maximum starting current 2 × rated motor current. Maximum starting time 15 seconds.*

Notes:

*Rated fuse current for **Y/Δ** starting also apply to the three-phase motors with slip-rings rotors.*
Use a larger fuse if the rated current or starting current is higher and/or if the starting time is longer.

The table applies to 'slow' and 'gL' fuses.

Moeller Enclosed motor starters & Isolators /www.moeller.co.uk/documents/starters_isolators.pdf

Appendix 5 – Extract of GL Rules 2008 - Low-voltage Switchgear Assemblies

Rules for Classification and Construction Ship Technology Edition 2008

Germanischer Lloyd

1 Seagoing Ships
3 Electrical Installations

Section 5
Low-Voltage Switchgear Assemblies

H. Testing of Switchboards and Switchgear

2.3.4 Insulation resistance measurement

The voltage test is to be followed by measurement of the resistance of insulation. The insulation resistance measurement is to be performed at a DC voltage of at least 500 V.

In large installations, the switchboard may be divided into a number of test sections for this purpose. The insulation resistance of each section shall be at least 1 M Ohm.

Section 20
Electrical Equipment

A. Electrical Machinery
The insulation resistance measurement shall be carried out at the end of the test sequence, with the machine at operating temperature, if possible. Minimum values of the measuring voltage and the insulation resistance shall be taken from Table 20.5.

Rated Voltage (V)	Measurement Voltage (V)	Insulation Resistance (MΩ)
Un ≤ 250	2 × Un	1
250 < Un ≤ 1000	500	1
1000 < Un ≤ 7200	1000	Un/1000 + 1
7200 < Un ≤ 15000	5000	Un/1000 + 1

Table 20.5 – Minimum values for measurement voltage and insulation resistance

E. Switchgear and Protection Devices

4. Protection devices

4.9 Insulation monitoring equipment

Devices for insulation monitoring of ships mains shall continuously monitor the insulation resistance of the network, and shall release an alarm should the insulation resistance of the system fall below 50 ohms per volt of the operating voltage. The measuring current shall not exceed 30 mA in the event of a dead short circuit to earth.

Germanischer Lloyd Rules and Regulations 2008 http://www.germanlloyd.org/

Appendix 6 – Extract of GL Rules 2008 - Switchgear and Protection Devices

Rules for Classification and Construction Ship Technology Edition 2008

Germanischer Lloyd

1 Seagoing Ships
3 Electrical Installations

Section 20
Electrical Equipment

E. Switchgear and Protection Devices

3. Low-voltage switchgear

3.1 Circuit-breakers

d) If the conditions for the closing operation are not fulfilled (eg undervoltage release not energised), switching-on shall not cause the contact pieces to come into contact.

4. Protection devices

4.1 Short-circuit protection
Short-circuit protection devices shall be independent of energy supplied from other circuits than those to be protected. In the event of a short circuit, the total break-down of the supply voltage shall be expected.

Short-circuit protection devices for generators shall be equipped with reclosing inhibitors, and shall be delayed for selective disconnection.

4.2 Overcurrent protection
The operation of overcurrent relays shall not be influenced by the ambient temperature. Thermal bimetallic relays shall be temperature compensated. Overcurrent relays for motor protection shall be adjustable and provided with a reclosing inhibitor.

4.3 Undervoltage protection
Undervoltage relays shall cause the circuit-breaker to open if the voltage drops to 70 % - 35 % of the rated voltage. Undervoltage relays of generator circuit-breakers shall have a delay up to 500 ms.

4.4 Shunt trips
Shunt trips shall ensure the disconnection of the circuit-breakers even if the voltage drops to 85 % of the rated voltage.

4.5 Electronic protection devices
Electronic protection devices shall remain operative at their maximum permissible load at an ambient temperature of 55°C.

4.6 Reverse power protection
The reverse power protection device shall respond to the active power regardless of the power factor, and shall operate only in the event of reverse power. The response value and pick up time shall be adjustable. The reverse power protection device shall remain operative despite a voltage drop to 60% of the rated value.

4.7 Phase failure protection
Protection devices for detection of a single-phase failure in three-phase circuits shall operate instantaneously. Bimetallic relays with differential release do not constitute phase failure protection devices in the opinion of these Rules.

4.9 Insulation monitoring equipment
Devices for insulation monitoring of ships mains shall continuously monitor the insulation resistance of the network, and shall release an alarm should the insulation resistance of the system fall below 50 ohms per volt of the operating voltage. The measuring current shall not exceed 30 mA in the event of a dead short circuit to earth.

This is an extract taken from GL regulations 2008 and must not be relied on or be considered all inclusive.

Appendix 7 – Extract of GL Rules 2008 - Power Supply Installations

Rules for Classification and Construction
Ship Technology
Edition 2008

1 Seagoing Ships
3 Electrical Installations

Section 3
Power Supply Installations

2. Rating and control of alternating and three-phase current generators of the main electrical power supply

2.1 Apparent power
The apparent power of three-phase generators shall be such that no inadmissible voltage drops occur in the ship's mains due to the normal starting currents of motors. The start-up of the motor with the greatest starting current shall not give rise to a voltage drop causing other consumers to malfunction. Where a number of generators operate in parallel, this condition shall continue to be met when the largest generator is not in operation.

2.3 Exciter equipment
Generators and their exciters are to be rated in such a way that:

- the generator can be loaded for two minutes at 150 % of its rated current with a power factor of 0,5 lagging (inductive) and still deliver approximately its rated voltage;
- the equipment is short-circuit-proof even having regard to the time lag of the generator circuit-breakers necessary to the selectivity of the system.

2.4 Regulating conditions
Under balanced load conditions, three-phase generators and their exciters are required to meet the following conditions (Emergency generators, see also C.1.6):

2.4.1 Steady regulating conditions
With the generator running at rated speed, the voltage shall not deviate from the rated value by more than 2,5 % from no-load up to the rated output and at the rated power factor after the transient reactions have ceased.

2.4.2 Transient regulating conditions
With the generator running at rated speed and rated voltage, the voltage shall neither fall below 85 % nor exceed 120 % of the rated value when symmetrical loads of specified current and power factor are suddenly applied or removed. The voltage shall regain its rated value 3 % in 1,5 seconds.

If no particular requirements are specified for the load changes, the above conditions are to be satisfied when the generator, running idle and excited to its rated voltage, is suddenly loaded to 60 % of its rated current with a power factor of < 0,4 (lagging), and, after steady-state operation has been achieved, the load is suddenly switched off again.

2.5 Load sharing during parallel operation
Where generators of the same output are operated in parallel, the reactive load of each machine shall not differ from its proportionate share by more than 10 % of its rated reactive power when the active load is shared equally.

In the case of generators running parallel with different ratings, the deviation from the proportionate share shall not exceed the lesser of the following values, assuming proportionately equal sharing of the active load:

- 10 % of the rated reactive power of the largest machine;
- 25 % of the rated reactive power of the smallest machine.

3. Design and equipment of generator prime movers

3.6 Parallel operation
3.6.1 The speed characteristics of prime movers shall be linear over the entire output range.

The governing characteristics of prime movers of units of the same output operating in parallel shall ensure that, over the range from 20 % to 100 % of the total active power, the share of each machine does not deviate from its proportionate share by more than 15 % of its rated active power.

4. Generators driven by the main propulsion plant (eg shaft-driven generators)

4.4 In case of frequency deviations exceeding 10 %, the generator is to be disconnected within 10-30 seconds.

5. Availability of the main electrical source

5.1 Where the main source of electrical power is necessary for propulsion and steering of the ship, the system shall be so arranged that the supply of the primary essential equipment will be maintained or immediately restored in the case of loss of any one of the generators in service.

5.2 To fulfill the demands named in 5.1, at least the following measures are required:

5.2.1 Automatic load shedding of the non-essential and, where necessary, secondary essential equipment to protect the generators against overload.

5.2.2 Automatic start-up of a stand-by unit on failure of the power supply. At least two units shall be provided according to Section 3, B. They shall be capable of reciprocal operation. The output of each unit shall be so rated as to ensure automatic start-up of the primary essential equipment. Where necessary, equipment may be switched on in staggered formation.

5.2.4 The automatic starting and connecting on of a generator and the primary essential equipment after black-out shall follow as quick as possible, but within not more than 30 seconds. Where diesel engines with longer starting times are used the starting and connecting times might be exceeded with approval of GL.

5.2.5 Where several generator units are required to cover the ship's power supply in permanent parallel operation, the failure of already one of the units shall cause the immediate trip of non-essential equipment and, where necessary, the secondary

essential equipment, where this is the only way to ensure that the remaining units can supply the primary essential equipment.

C. Emergency Electrical Power Supply

1. General requirements

1.1 The emergency source of electrical power shall take over the supply of the emergency consumers in case of failure of the main source of electrical power. It shall be independent of the main source of electrical power.

1.5 For all equipment forming part of the emergency source of electrical power, provision shall be made for periodic functional tests, including especially the testing of automatic switching and starting devices. Such testing shall be possible without interfering with other aspects of the ship's operation.

3. Emergency electrical power supply on cargo ships

3.1 All cargo ships of 500 GRT and over are to be provided with a self-contained emergency source of electrical power.

3.2 With due allowance for starting currents, the emergency source of electrical power shall be capable of simultaneously supplying at least the following services for the period specified below, if their operation depends upon an electrical source.

3.2.1 For 3 hours, the emergency lighting at every embarkation station for survival craft and rescue boats on deck and along the ship's sides in this area.

3.2.2 For 18 hours, the emergency lighting

a) in all service and accommodation alleyways, on stairways, at exits and in personnel lift cars and shafts;
b) in engine rooms and main generator stations including their control positions;
c) in all control stations, bridge, engine control rooms and at each main and emergency switchboard;
d) at all stowage positions for firemen's outfits;
e) in the steering gear compartment, and the CO_2 room;
f) at the fire pump mentioned in 3.2.5, at the sprinkler pump, if any, the emergency bilge pump, if any, and at the start-up position for their motors;
g) in all cargo pump-rooms of tankers.

3.2.3 For 18 hours
a) the navigation lights and other lights required by the current "International Regulations for Preventing Collisions at Sea";
b) the VHF radio installation required in SOLAS IV and, where provided, the MF radio installation, as well as the ship earth station and the MF/RF radio installation.

3.2.4 For 18 hours
a) all internal signaling and communications equipment required in an emergency;
b) all ship's navigational appliances stipulated by SOLAS V/12;
c) the fire detection and fire alarm system;
d) the intermittent operation of the daylight signaling lamp, the ship's whistle, the manually operated fire alarms and all the internal signals required in an emergency, eg general alarm, and CO_2 alarm unless these services can be independently supplied during this 18-hour period by an emergency storage battery.

3.2.5 For 18 hours
a) the required emergency fire pump and the water-spray installations;
b) the auxiliary equipment for the emergency generator set;
c) at least one bilge pump for cargo spaces on open-top container ships.

3.4.1 Where the emergency source of electrical power is a generator set, it shall be driven by a suitable prime mover with its own independent fuel supply in accordance with Chapter 2 – Machinery Installations, Section 10 and with an independent cooling system.

The emergency supply of electrical power shall come into operation as quickly as possible, and in any event not later than 45 seconds after the failure of the main source of electrical power.

D. Operation of the emergency generator in port

1. General

The emergency generator may be used during lay time in the harbour for the main power supply, provided the undermentioned requirements are complied with (see also C.1.3).

2. Requirements

2.1 The independence of the emergency power supply from other auxiliaries of the main engine plant shall be ensured during maneuvering in port, during estuary trading and during sea service.

2.2 The emergency diesel-generator shall be protected against overload. Disconnection of the transfer line for shedding of non-emergency load shall be provided to ensure continued safe operation of the generator set.

2.3 The emergency power supply installations shall be arranged and protected in such a way that an interruption of cables, as short circuit or an earth-fault caused by fire or by another event neither in spaces where the components of main electrical power supply with their associated accessories are installed nor in other machinery spaces of category A will not interfere with control, monitoring, auxiliary power supply and power distribution of the emergency electrical power supply.

If required for safe operation selector switches with switching positions port operation – emergency operation shall be provided in the emergency switchboard, see Section 5, C.3.2.

3. Operation manual

An operation manual shall be provided on board containing the conditions for the operation and ensure that when the vessel is under way all control devices (eg valves, switches) are in a correct position for the independent emergency operation of the emergency generator set and emergency switchboard.

Note *This operation manual shall also contain information on required fuel oil tank level, position of harbor/sea mode switch if fitted, ventilation openings etc.*

Section 4
Installation Protection and Power Distribution

A. Three-Phase Main Generators

1.2 Parallel operation
In parallel operation, the generators supply a common busbar system of the main switchboard, to which the consumer feeders are connected.

2. Protection equipment

2.1.1 Generators shall be at least protected against damage due to short circuits and overloads.

2.2 Short-circuit protection
2.2.1 The short-circuit protection is to be set at an overcurrent of more than 50 %, but at a value less than the steady short-circuit current. It shall have a short time delay compatible with the selectivity of the system (up to about 500 ms).

2.2.2 The short circuit protection shall not be disabled by undervoltage.

2.3 Overload protection
2.3.1 The overload protection, which is to be set to a value between 10 % and 50 % overcurrent, shall trip the generator circuit-breaker with a time delay of not more than 2 minutes. A setting above 50% overcurrent may be allowed, where this is required by the working conditions and is compatible with the generator characteristics. The overload protection shall not impair immediate reconnection of the generator.

2.4 Reverse-power protection
2.4.1 Generators from 50 kVA output upwards provided for parallel operation are to be protected by a delayed reverse-power release.

2.4.2 The protection shall be selected and set in accordance with the characteristics of the prime mover. Setting guidance values are: for turbogenerators 2% to 6%, for diesel generators 8% to 15% of the rated output delayed from 2 to 5 seconds.

The setting should, if possible be at 50 % of the tractive power of the prime mover. Should the operating voltages decrease to 50 % of the rated value, the reverse-power protection shall remain effective within the limits stated.

2.5 Undervoltage protection
Generator circuit-breakers are to be provided with under-voltage protection. In the event of a decrease of the voltage to 70 % – 35 % of the rated voltage, the generator circuit-breaker shall open automatically. Undervoltage releases shall have a short-time delay adapted to the short circuit protection.

2.6 Over-voltage protection
The ship's mains shall be protected against overvoltage. The voltage shall be limited to 130 % UN and max. 5 s even in the case of failure of the voltage regulators.

2.7 Underfrequency protection
2.7.1 In the event of a continuous frequency drop of more than 10 %, the non-essential and, where necessary, the secondary essential equipment shall be tripped within 5 to 10 s. If this fails to establish normal operating condition, the supplying generators shall be disconnected from the power supply so that the stand-by unit can cut in.

2.7.2 For shaft-driven generator plants protection shall be provided in accordance with Section 3, B.4 for disconnecting the generators in the event of underfrequency.

2.8 Testing
Generator protection devices are subject to mandatory type approvals.

3.3 Parallel operation
The following devices are to be provided:

- For each generator, a three-pole circuit-breaker with delayed overcurrent- and short-timedelayed short-circuit and undervoltage release;
- In the case of generators intended for parallel operation, the generator switch is to be provided with undervoltage protection which prevents closing of the switch if the generator is dead;
- A single-fault event in the synchronization circuit or in the black-out monitoring shall not lead to an asynchronous connection.

B. Emergency Three-Phase Generators

Emergency generators supply the emergency switchboards and the connected emergency consumers.

1. Protective equipment and switchgear

Generator protection shall consist of at least:

- short circuit protection
- overload protection
- undervoltage protection.

However it is permissible for the overload protection not to disconnect the generator automatically but instead to trigger an optical and acoustical warning signal at the emergency switchboard and at the main switchboard.

I. Power Distribution

8. Emergency shutdown facilities

Emergency shutdown facilities placed outside the sites at which the equipment is installed are to be provided for the following consumers. The consumers may be arranged in groups, provided that redundant consumers are allocated to at least two electrically independent groups. Emergency shutdown facilities are to be provided for eg

- fuel pumps;
- lubrication oil pumps;
- oil burner plants;
- separators;
- fan motors;
- boiler blowers;
- auxiliary blowers for main engines;
- thermal oil pumps (see Chapter 2 – Machinery Installations, Section 12, B.9.)

This is an extract taken from GL regulations 2008 and must not be relied on.

Appendix 8 – Thermocouples J & K Reference Table

Type J (0 - 750°C) Thermoelectric voltage in mV

°C	0	1	2	3	4	5	6	7	8	9	10
0	0.000	0.050	0.101	0.151	0.202	0.253	0.303	0.354	0.405	0.456	0.507
10	0.507	0.558	0.609	0.660	0.711	0.762	0.814	0.865	0.916	0.968	1.019
20	1.019	1.071	1.122	1.174	1.226	1.277	1.329	1.381	1.433	1.485	1.537
30	1.537	1.589	1.641	1.693	1.745	1.797	1.849	1.902	1.954	2.006	2.059
40	2.059	2.111	2.164	2.216	2.269	2.322	2.374	2.427	2.480	2.532	2.585
50	2.585	2.638	2.691	2.744	2.797	2.850	2.903	2.956	3.009	3.062	3.116
60	3.116	3.169	3.222	3.275	3.329	3.382	3.436	3.489	3.543	3.596	3.650
70	3.650	3.703	3.757	3.810	3.864	3.918	3.971	4.025	4.079	4.133	4.187
80	4.187	4.240	4.294	4.348	4.402	4.456	4.510	4.564	4.618	4.672	4.726
90	4.726	4.781	4.835	4.889	4.943	4.997	5.052	5.106	5.160	5.215	5.269
100	5.269	5.323	5.378	5.432	5.487	5.541	5.595	5.650	5.705	5.759	5.814
110	5.814	5.868	5.923	5.977	6.032	6.087	6.141	6.196	6.251	6.306	6.360
120	6.360	6.415	6.470	6.525	6.579	6.634	6.689	6.744	6.799	6.854	6.909
130	6.909	6.964	7.019	7.074	7.129	7.184	7.239	7.294	7.349	7.404	7.459
140	7.459	7.514	7.569	7.624	7.679	7.734	7.789	7.844	7.900	7.955	8.010
150	8.010	8.065	8.120	8.175	8.231	8.286	8.341	8.396	8.452	8.507	8.562
160	8.562	8.618	8.673	8.728	8.783	8.839	8.894	8.949	9.005	9.060	9.115
170	9.115	9.171	9.226	9.282	9.337	9.392	9.448	9.503	9.559	9.614	9.669
180	9.669	9.725	9.780	9.836	9.891	9.947	10.002	10.057	10.113	10.168	10.224
190	10.224	10.279	10.335	10.390	10.446	10.501	10.557	10.612	10.668	10.723	10.779
200	10.779	10.834	10.890	10.945	11.001	11.056	11.112	11.167	11.223	11.278	11.334
210	11.334	11.389	11.445	11.501	11.556	11.612	11.667	11.723	11.778	11.834	11.889
220	11.889	11.945	12.000	12.056	12.111	12.167	12.222	12.278	12.334	12.389	12.445
230	12.445	12.500	12.556	12.611	12.667	12.722	12.778	12.833	12.889	12.944	13.000
240	13.000	13.056	13.111	13.167	13.222	13.278	13.333	13.389	13.444	13.500	13.555
250	13.555	13.611	13.666	13.722	13.777	13.833	13.888	13.944	13.999	14.055	14.110
260	14.110	14.166	14.221	14.277	14.332	14.388	14.443	14.499	14.554	14.609	14.665
270	14.665	14.720	14.776	14.831	14.887	14.942	14.998	15.053	15.109	15.164	15.219
280	15.219	15.275	15.330	15.386	15.441	15.496	15.552	15.607	15.663	15.718	15.773
290	15.773	15.829	15.884	15.940	15.995	16.050	16.106	16.161	16.216	16.272	16.327
300	16.327	16.383	16.438	16.493	16.549	16.604	16.659	16.715	16.770	16.825	16.881
310	16.881	16.936	16.991	17.046	17.102	17.157	17.212	17.268	17.323	17.378	17.434
320	17.434	17.489	17.544	17.599	17.655	17.710	17.765	17.820	17.876	17.931	17.986
330	17.986	18.041	18.097	18.152	18.207	18.262	18.318	18.373	18.428	18.483	18.538
340	18.538	18.594	18.649	18.704	18.759	18.814	18.870	18.925	18.980	19.035	19.090
350	19.090	19.146	19.201	19.256	19.311	19.366	19.422	19.477	19.532	19.587	19.642
360	19.642	19.697	19.753	19.808	19.863	19.918	19.973	20.028	20.083	20.139	20.194
370	20.194	20.249	20.304	20.359	20.414	20.469	20.525	20.580	20.635	20.690	20.745
380	20.745	20.800	20.855	20.911	20.966	21.021	21.076	21.131	21.186	21.241	21.297
390	21.297	21.352	21.407	21.462	21.517	21.572	21.627	21.683	21.738	21.793	21.848
400	21.848	21.903	21.958	22.014	22.069	22.124	22.179	22.234	22.289	22.345	22.400
410	22.400	22.455	22.510	22.565	22.620	22.676	22.731	22.786	22.841	22.896	22.952
420	22.952	23.007	23.062	23.117	23.172	23.228	23.283	23.338	23.393	23.449	23.504
430	23.504	23.559	23.614	23.670	23.725	23.780	23.835	23.891	23.946	24.001	24.057
440	24.057	24.112	24.167	24.223	24.278	24.333	24.389	24.444	24.499	24.555	24.610
450	24.610	24.665	24.721	24.776	24.832	24.887	24.943	24.998	25.053	25.109	25.164
460	25.164	25.220	25.275	25.331	25.386	25.442	25.497	25.553	25.608	25.664	25.720
470	25.720	25.775	25.831	25.886	25.942	25.998	26.053	26.109	26.165	26.220	26.276
480	26.276	26.332	26.387	26.443	26.499	26.555	26.610	26.666	26.722	26.778	26.834
490	26.834	26.889	26.945	27.001	27.057	27.113	27.169	27.225	27.281	27.337	27.393
500	27.393	27.449	27.505	27.561	27.617	27.673	27.729	27.785	27.841	27.897	27.953
510	27.953	28.010	28.066	28.122	28.178	28.234	28.291	28.347	28.403	28.460	28.516
520	28.516	28.572	28.629	28.685	28.741	28.798	28.854	28.911	28.967	29.024	29.080
530	29.080	29.137	29.194	29.250	29.307	29.363	29.420	29.477	29.534	29.590	29.647
540	29.647	29.704	29.761	29.818	29.874	29.931	29.988	30.045	30.102	30.159	30.216
550	30.216	30.273	30.330	30.387	30.444	30.502	30.559	30.616	30.673	30.730	30.788
560	30.788	30.845	30.902	30.960	31.017	31.074	31.132	31.189	31.247	31.304	31.362
570	31.362	31.419	31.477	31.535	31.592	31.650	31.708	31.766	31.823	31.881	31.939
580	31.939	31.997	32.055	32.113	32.171	32.229	32.287	32.345	32.403	32.461	32.519
590	32.519	32.577	32.636	32.694	32.752	32.810	32.869	32.927	32.985	33.044	33.102

600	33.102	33.161	33.219	33.278	33.337	33.395	33.454	33.513	33.571	33.630	33.689
610	33.689	33.748	33.807	33.866	33.925	33.984	34.043	34.102	34.161	34.220	34.279
620	34.279	34.338	34.397	34.457	34.516	34.575	34.635	34.694	34.754	34.813	34.873
630	34.873	34.932	34.992	35.051	35.111	35.171	35.230	35.290	35.350	35.410	35.470
640	35.470	35.530	35.590	35.650	35.710	35.770	35.830	35.890	35.950	36.010	36.071
650	36.071	36.131	36.191	36.252	36.312	36.373	36.433	36.494	36.554	36.615	36.675
660	36.675	36.736	36.797	36.858	36.918	36.979	37.040	37.101	37.162	37.223	37.284
670	37.284	37.345	37.406	37.467	37.528	37.590	37.651	37.712	37.773	37.835	37.896
680	37.896	37.958	38.019	38.081	38.142	38.204	38.265	38.327	38.389	38.450	38.512
690	38.512	38.574	38.636	38.698	38.760	38.822	38.884	38.946	39.008	39.070	39.132
700	39.132	39.194	39.256	39.318	39.381	39.443	39.505	39.568	39.630	39.693	39.755
710	39.755	39.818	39.880	39.943	40.005	40.068	40.131	40.193	40.256	40.319	40.382
720	40.382	40.445	40.508	40.570	40.633	40.696	40.759	40.822	40.886	40.949	41.012
730	41.012	41.075	41.138	41.201	41.265	41.328	41.391	41.455	41.518	41.581	41.645
740	41.645	41.708	41.772	41.835	41.899	41.962	42.026	42.090	42.153	42.217	42.281
750	42.281	42.344	42.408	42.472	42.536	42.599	42.663	42.727	42.791	42.855	42.919

Type K (-200 - 1260°C) Thermoelectric voltage in mV

°C	0	1	2	3	4	5	6	7	8	9	10
0	0.000	0.039	0.079	0.119	0.158	0.198	0.238	0.277	0.317	0.357	0.397
10	0.397	0.437	0.477	0.517	0.557	0.597	0.637	0.677	0.718	0.758	0.798
20	0.798	0.838	0.879	0.919	0.960	1.000	1.041	1.081	1.122	1.163	1.203
30	1.203	1.244	1.285	1.326	1.366	1.407	1.448	1.489	1.530	1.571	1.612
40	1.612	1.653	1.694	1.735	1.776	1.817	1.858	1.899	1.941	1.982	2.023
50	2.023	2.064	2.106	2.147	2.188	2.230	2.271	2.312	2.354	2.395	2.436
60	2.436	2.478	2.519	2.561	2.602	2.644	2.685	2.727	2.768	2.810	2.851
70	2.851	2.893	2.934	2.976	3.017	3.059	3.100	3.142	3.184	3.225	3.267
80	3.267	3.308	3.350	3.391	3.433	3.474	3.516	3.557	3.599	3.640	3.682
90	3.682	3.723	3.765	3.806	3.848	3.889	3.931	3.972	4.013	4.055	4.096
100	4.096	4.138	4.179	4.220	4.262	4.303	4.344	4.385	4.427	4.468	4.509
110	4.509	4.550	4.591	4.633	4.674	4.715	4.756	4.797	4.838	4.879	4.920
120	4.920	4.961	5.002	5.043	5.084	5.124	5.165	5.206	5.247	5.288	5.328
130	5.328	5.369	5.410	5.450	5.491	5.532	5.572	5.613	5.653	5.694	5.735
140	5.735	5.775	5.815	5.856	5.896	5.937	5.977	6.017	6.058	6.098	6.138
150	6.138	6.179	6.219	6.259	6.299	6.339	6.380	6.420	6.460	6.500	6.540
160	6.540	6.580	6.620	6.660	6.701	6.741	6.781	6.821	6.861	6.901	6.941
170	6.941	6.981	7.021	7.060	7.100	7.140	7.180	7.220	7.260	7.300	7.340
180	7.340	7.380	7.420	7.460	7.500	7.540	7.579	7.619	7.659	7.699	7.739
190	7.739	7.779	7.819	7.859	7.899	7.939	7.979	8.019	8.059	8.099	8.138
200	8.138	8.178	8.218	8.258	8.298	8.338	8.378	8.418	8.458	8.499	8.539
210	8.539	8.579	8.619	8.659	8.699	8.739	8.779	8.819	8.860	8.900	8.940
220	8.940	8.980	9.020	9.061	9.101	9.141	9.181	9.222	9.262	9.302	9.343
230	9.343	9.383	9.423	9.464	9.504	9.545	9.585	9.626	9.666	9.707	9.747
240	9.747	9.788	9.828	9.869	9.909	9.950	9.991	10.031	10.072	10.113	10.153
250	10.153	10.194	10.235	10.276	10.316	10.357	10.398	10.439	10.480	10.520	10.561
260	10.561	10.602	10.643	10.684	10.725	10.766	10.807	10.848	10.889	10.930	10.971
270	10.971	11.012	11.053	11.094	11.135	11.176	11.217	11.259	11.300	11.341	11.382
280	11.382	11.423	11.465	11.506	11.547	11.588	11.630	11.671	11.712	11.753	11.795
290	11.795	11.836	11.877	11.919	11.960	12.001	12.043	12.084	12.126	12.167	12.209
300	12.209	12.250	12.291	12.333	12.374	12.416	12.457	12.499	12.540	12.582	12.624
310	12.624	12.665	12.707	12.748	12.790	12.831	12.873	12.915	12.956	12.998	13.040
320	13.040	13.081	13.123	13.165	13.206	13.248	13.290	13.331	13.373	13.415	13.457
330	13.457	13.498	13.540	13.582	13.624	13.665	13.707	13.749	13.791	13.833	13.874
340	13.874	13.916	13.958	14.000	14.042	14.084	14.126	14.167	14.209	14.251	14.293
350	14.293	14.335	14.377	14.419	14.461	14.503	14.545	14.587	14.629	14.671	14.713
360	14.713	14.755	14.797	14.839	14.881	14.923	14.965	15.007	15.049	15.091	15.133
370	15.133	15.175	15.217	15.259	15.301	15.343	15.385	15.427	15.469	15.511	15.554
380	15.554	15.596	15.638	15.680	15.722	15.764	15.806	15.849	15.891	15.933	15.975
390	15.975	16.017	16.059	16.102	16.144	16.186	16.228	16.270	16.313	16.355	16.397
400	16.397	16.439	16.482	16.524	16.566	16.608	16.651	16.693	16.735	16.778	16.820
410	16.820	16.862	16.904	16.947	16.989	17.031	17.074	17.116	17.158	17.201	17.243
420	17.243	17.285	17.328	17.370	17.413	17.455	17.497	17.540	17.582	17.624	17.667
430	17.667	17.709	17.752	17.794	17.837	17.879	17.921	17.964	18.006	18.049	18.091

440	18.091	18.134	18.176	18.218	18.261	18.303	18.346	18.388	18.431	18.473	18.516
450	18.516	18.558	18.601	18.643	18.686	18.728	18.771	18.813	18.856	18.898	18.941
460	18.941	18.983	19.026	19.068	19.111	19.154	19.196	19.239	19.281	19.324	19.366
470	19.366	19.409	19.451	19.494	19.537	19.579	19.622	19.664	19.707	19.750	19.792
480	19.792	19.835	19.877	19.920	19.962	20.005	20.048	20.090	20.133	20.175	20.218
490	20.218	20.261	20.303	20.346	20.389	20.431	20.474	20.516	20.559	20.602	20.644
500	20.644	20.687	20.730	20.772	20.815	20.857	20.900	20.943	20.985	21.028	21.071
510	21.071	21.113	21.156	21.199	21.241	21.284	21.326	21.369	21.412	21.454	21.497
520	21.497	21.540	21.582	21.625	21.668	21.710	21.753	21.796	21.838	21.881	21.924
530	21.924	21.966	22.009	22.052	22.094	22.137	22.179	22.222	22.265	22.307	22.350
540	22.350	22.393	22.435	22.478	22.521	22.563	22.606	22.649	22.691	22.734	22.776
550	22.776	22.819	22.862	22.904	22.947	22.990	23.032	23.075	23.117	23.160	23.203
560	23.203	23.245	23.288	23.331	23.373	23.416	23.458	23.501	23.544	23.586	23.629
570	23.629	23.671	23.714	23.757	23.799	23.842	23.884	23.927	23.970	24.012	24.055
580	24.055	24.097	24.140	24.182	24.225	24.267	24.310	24.353	24.395	24.438	24.480
590	24.480	24.523	24.565	24.608	24.650	24.693	24.735	24.778	24.820	24.863	24.905
600	24.905	24.948	24.990	25.033	25.075	25.118	25.160	25.203	25.245	25.288	25.330
610	25.330	25.373	25.415	25.458	25.500	25.543	25.585	25.627	25.670	25.712	25.755
620	25.755	25.797	25.840	25.882	25.924	25.967	26.009	26.052	26.094	26.136	26.179
630	26.179	26.221	26.263	26.306	26.348	26.390	26.433	26.475	26.517	26.560	26.602
640	26.602	26.644	26.687	26.729	26.771	26.814	26.856	26.898	26.940	26.983	27.025
650	27.025	27.067	27.109	27.152	27.194	27.236	27.278	27.320	27.363	27.405	27.447
660	27.447	27.489	27.531	27.574	27.616	27.658	27.700	27.742	27.784	27.826	27.869
670	27.869	27.911	27.953	27.995	28.037	28.079	28.121	28.163	28.205	28.247	28.289
680	28.289	28.332	28.374	28.416	28.458	28.500	28.542	28.584	28.626	28.668	28.710
690	28.710	28.752	28.794	28.835	28.877	28.919	28.961	29.003	29.045	29.087	29.129
700	29.129	29.171	29.213	29.255	29.297	29.338	29.380	29.422	29.464	29.506	29.548
710	29.548	29.589	29.631	29.673	29.715	29.757	29.798	29.840	29.882	29.924	29.965
720	29.965	30.007	30.049	30.090	30.132	30.174	30.216	30.257	30.299	30.341	30.382
730	30.382	30.424	30.466	30.507	30.549	30.590	30.632	30.674	30.715	30.757	30.798
740	30.798	30.840	30.881	30.923	30.964	31.006	31.047	31.089	31.130	31.172	31.213
750	31.213	31.255	31.296	31.338	31.379	31.421	31.462	31.504	31.545	31.586	31.628

Appendix 9 – Resistors' and Capacitors' Coding and Marking System

Resistors' colour code

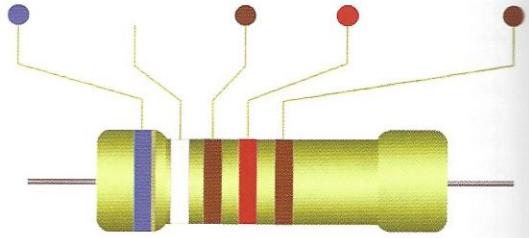
The resistors' colour code is a standard in both the electronics and electrical industries, indicating the value of resistance of a resistor. Coloured bands are painted around the resistor.

Figure 1 – Resistors' colour code example

Each coloured band represents a number and the order of the coloured bands represents a value. In most cases there are four bands. However, certain precision resistors have five bands or have the values written on them refining the tolerance value further. The first three coloured bands indicate a number. The fourth band indicates the multiplier or, in other words, the number of zeros.

The fifth band indicates the tolerance of the resistance as a percentage and varies from one manufacturer to another according to their own standards.

Colour	1. digit	2. digit	3. digit	Multiplier	Tolerance
Silver				× 0.01	10%
Gold				× 0.1	5%
Black	0	0	0	× 1	20%
Brown	1	1	1	× 10	1%
Red	2	2	2	× 100	2%
Orange	3	3	3	× 1k	–
Yellow	4	4	4	× 10k	–
Green	5	5	5	× 100k	0.5%
Blue	6	6	6	× 1M	0.25%
Violet	7	7	7	× 10M	0.1%
Grey	8	8	8	× 100M	0.1%
White	9	9	9	× 1G	–



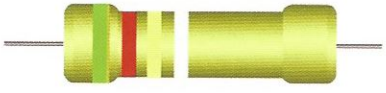
The following are a few examples of colour coded resistors:

A resistor coloured Blue-Brown-Green-Silver-Blue would be 6.15Ω with a tolerance of +/- 0.25%.

A resistor coloured Brown-Green-Grey-Silver-Red would be 1.58Ω with a tolerance of +/-2%.

A resistor coloured Orange-Orange-Black-Brown-Violet would be 3.3kΩ with a tolerance of +/- 0.1%.

A resistor coloured Yellow-Violet-Orange-Gold would be 47kΩ with a tolerance of +/- 5%.



A resistor coloured Green-Red-Gold-Silver would be 5.2Ω with a tolerance of +/- 10%.

A resistor coloured White-Violet-Black would be 97Ω with a tolerance of +/-20%. When there are only three colour bands on a resistor it is in fact a 4-band code with a blank (20%) tolerance band.

Capacitor markings

Capacitors are marked with codes to indicate the value, tolerance and material.

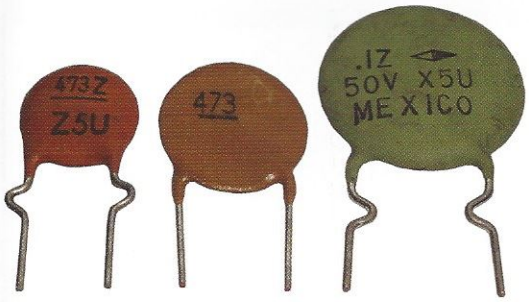


Figure 2 – Capacitors' markings

Value Codes

The capacitance value is marked using a three digit code, which works in the same way as resistor coding, but uses numbers instead of colours.

The first two numbers give the value and the last number provides the multiplier. This provides the capacitance value in Picofarads (pF). For example, the code 103 would be interpreted as:

Code 103 = 1 – 0 – 000 pF
= 10,000 pF
= 0.01 mF

Alternatively, the value may be marked directly, for example 2n2 would be read directly as 2.2 Nanofarads (nF).

Tolerance Code

A single letter is often used to indicate the tolerance of a component. These can be translated using the following table:

Tolerance Code	Tolerance
C	+/- 0.25pF
D	+/- 0.5pF
F	+/- 1%
G	+/- 2%
J	+/- 5%
K	+/- 10%
M	+/- 20%
Z	- 20% +80%

Material Code

The dielectric material is marked in abbreviated form. The table below shows the meaning of these abbreviations.

Marking	Material
MKT	Metallised Polyester (PETP)
MKC	Metallised Polycarbonate
KT	Polyester Film/Foil
KS	Polystyrene Film/Foil
KP	Polypropylene Film/Foil
MKP	Metallised Polypropylene

Appendix 10 – Conversions and Prefixes

Voltage Conversions

To convert	To	Multiply by
Rms	*Average*	*.9*
Rms	*Peak*	*1.414*
Average	*Rms*	*1.111*
Average	*Peak*	*1.567*
Peak	*Rms*	*.707*
Peak	*Average*	*.637*
Peak	*Peak-to-Peak*	*2*

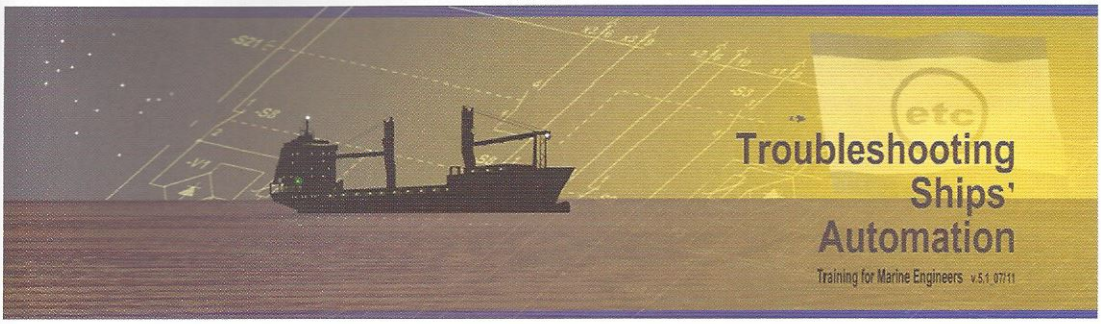
Common Prefixes

Symbol	Prefix	Equivalent
G	*giga*	*1,000,000,000*
M	*mega*	*1,000,000*
K	*kilo*	*1000*
base unit	*-*	*1*
m	*milli*	*0.001*
μ	*micro*	*0.000001*
n	*nano*	*0.000000001*
p	*pico*	*0.000000000001*
z	*impedance*	*Ohms - Ω*

Finally...

You should not read any book expecting to become an instant expert. What it can do is equip you with the information that will assist you in becoming one. Through diligence and practice, adapting what you have learned to the unique situations that you encounter, your skills will improve.

It may be that you are unable to practice every aspect of your knowledge each day, but whatever your position or circumstance, it is important to develop a habit of learning whenever the opportunity arises.



Training that Works... for Engineers who Work Onboard

Modern ships have become increasingly automated and this has raised awareness of the inadequacy of existing seafarers' automation education and training. Should any aspect of the automation fail, the crew are often not trained to use alternative systems or respond effectively. A second problem has arisen from a review of the arguments from the IMO Maritime Safety Committee (reports MSC 82.15/2 and MSC 82/15/3, 2006), suggesting that operators rarely understand all the characteristics of automatic systems or their weaknesses and limitations, which has been a significant factor in marine accidents.

Problems encountered with the application of automated systems and failures of any aspect of automation and processor-based gears' starters will be factors that contribute to future marine incidents. It is therefore essential that Marine Engineers and ETOs have a good understanding of these systems and ensure that they are maintained in an efficient and safe operational condition. This can be achieved by upgrading the knowledge and skills of all onboard fleet engineers, who have to deal with the ever-changing demands of new ships' building technology, through training programmes.

The draft training programme, Troubleshooting Ships' Automation, was implemented in 2003, as a result of pressure from shipowners, with the aim of helping Marine Engineers comply with the STCW Regulations and the company's SMS while operating without an ETO, and to improve their understanding and troubleshooting capabilities of modern ships' applications. It was also designed to give personnel who lack the necessary troubleshooting skills an opportunity to develop them and feedback from the fleet technical inspections suggest that this training has proved to be highly efficient in achieving this.

Despite this success and to keep training in line with new buildings, the updated version of TSA v.5.1 was reinforced with interactive flash-based simulators of the modern el.gears' starters as well as power plants. The curriculum includes a wide range of topics, from basics such as "how to read electrical diagrams" and "control circuit elements" to complex subjects such as microprocessors and the skills required for maintenance and troubleshooting.

This training would be appropriate for the following personnel:

- Management level Marine Engineers
- Operational level Marine Engineers
- Electricians with a lack of experience and practical skills
- Engineers' and el. Engineers' apprentices.

With best regards
Alexandr Yakimchuk
TSA developer and executive trainer

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There are numerous people without whom this book might never have been written. Among those who deserve credit is the first reader *Raimund Wittenberg* for sharing his ideas throughout this book.

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  Service Technician Repropel CO. Lisbon, Portugal
- Stöhrfeldt Kurt
  Senior Lead Surveyour Germanischer Lloyd. Miami, USA
- Voloshyn Sergey
  Technical Superintendent Marlow Navigation. Limassol, Cyprus
- Vovk Igor
  Chief Engineer Marlow Navigation. Odessa, Ukraine
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  Technical Superintendent Jüngerhans Maritime Services. Haren Ems, Germany
- Yanyev Sergey
  Chief Engineer Marlow Navigation. Odessa, Ukraine

I'd also like to thank my family who continue to support me while I put in the work to produce this book and for not disowning me in the process.

Should there be any unintentional omissions, do forgive me…

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